Volume 15 OCTOBER 1931 Number 10

BULLETIN
of the
American Association *of* Petroleum Geologists

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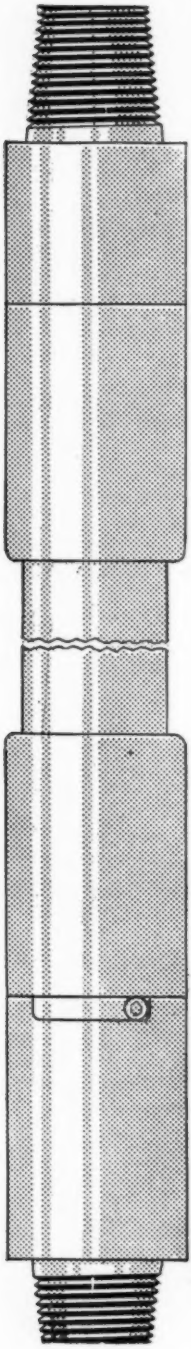

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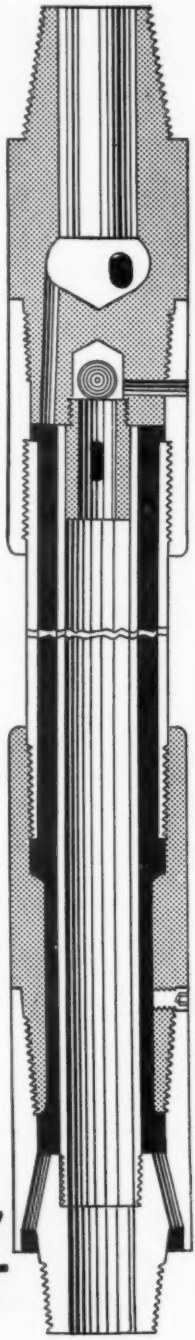

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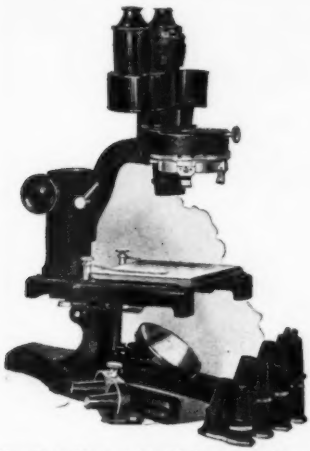

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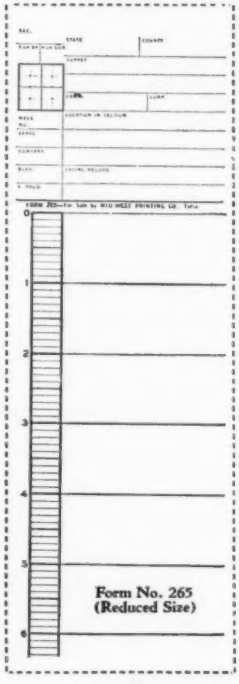

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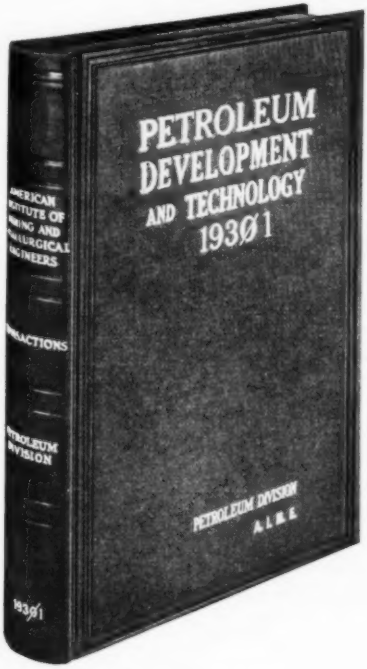

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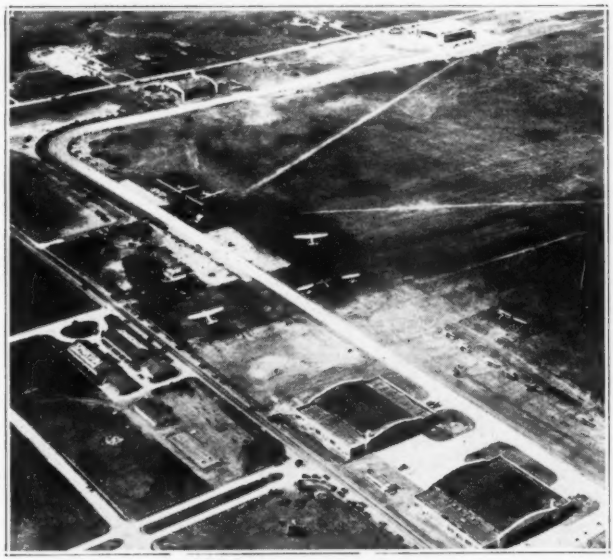

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DONALDSON BOGART DOWLING

(Courtesy of the Royal Society of Canada, Ottawa, Canada)

DONALDSON BOGART DOWLING

This symposium on the stratigraphy of the plains of southern Alberta has been dedicated by the Alberta Society of Petroleum Geologists as a memorial to the late Dr. Donaldson Bogart Dowling.

Dr. Dowling was born on November 5, 1858, in Ontario. He graduated from McGill University in 1883 with the degree of bachelor of applied science, and he received a gold medal for the highest general standing in his class. In 1884 he joined the Geological Survey of Canada, where he rendered signal service until his death on May 26, 1925.

In recognition of his ability and the valuable services he had rendered his country he was given the honorary degree of doctor of science by his Alma Mater in 1921. He was elected a fellow of the Royal Society of Canada in 1912 and was made vice-president of the Geology Section in 1925, a few days prior to his death. In 1918 he was elected president of the Canadian Institute of Mining and Metallurgy. His thoughtful counsel, as a member of the Geographic Board of Canada, is not the least of his achievements. He was a member of the Dominion Power Board, which was organized in 1918 to advise the Federal Government on water power and water data. From this organization the present Water Powers Branch and later the Irrigation Branch of the Department of the Interior were created. For many years he served with distinction as a member of the Dominion Fuel Board.

When Dr. Dowling entered the Geological Survey of Canada in 1884, western Canada was attracting attention through the efforts of early explorers and fur traders. The first 15 years of his field experience were spent in geological and geographical explorations in the western plains and in northern Manitoba and Ontario. Much of the remainder of his life was devoted to the geology of the plains area in Alberta, Saskatchewan, and Manitoba, where coal, petroleum, and natural gas are the prime mineral resources. He soon became the authority on these mineral products not only in the Great Plains but throughout the whole of Canada. His publications on the coal resources of Canada are classics to-day and his knowledge of coal resources placed him as the leading author of a four-volume work entitled "Coal Resources of the World," compiled for and issued by the Twelfth International Geological Congress in 1913. In this work he included his system of coal classification, which ranks favorably with the many others that are widely known to-day.

In Alberta Dr. Dowling is probably best known by two masterly works, the "Cascade Coal Basin," and the geology of "The Southern Plains of Alberta." Dowling's classic work on the southern plains is either referred to or reflected in all of the papers in this memorial. It can be said without fear of contradiction that Dr. Dowling laid the foundation for the study of stratigraphy and structural geology in southern Alberta.

No more fitting memorial could be erected to the eminent geologist, gentleman, and friend than the dedication of this volume of the results obtained by the careful, painstaking, and thorough geologists who have contributed and who are continuing the researches so ably established by the life work of Dr. Dowling.

As a result of his geological knowledge of southern Alberta, he discovered in 1915 an artesian water supply for the great dry belt of that region.

The acquaintance and association of both writers of this note with Dr. Dowling dates back to 1906. Both have worked under his guidance in Alberta. Many incidents are worthy of record if space would permit. Among his many outstanding characteristics might be mentioned the fact that he always gave kindly audience to his associates and assistants. In all our relations with him we never heard him express an unkind remark about anyone. He was most temperate in his consideration of others and of their opinions, no matter how adverse to his own. His genial manner attracted all who knew him.

Although an energetic worker in his scientific pursuits, he found time for the higher and finer things of life, being a lover of music, art, and literature, and himself an artist of no mean order.

JOHN A. ALLAN
S. E. SLIPPER

Donaldson Bogart Dowling Memorial Symposium on Stratigraphy of Plains of Southern Alberta

FOREWORD

The exacting requirements of petroleum geology have of late given rise to detailed measurements of surface sections and painstaking studies of deep-well and test-hole samples in the plains of southern Alberta. These studies have materially added to the knowledge of the stratigraphy of this region. It was suggested by B. F. Hake, president during 1930 of the Alberta Society of Petroleum Geologists, that this knowledge be brought together in a symposium on the stratigraphy of the plains of southern Alberta. This was done, and the papers comprising it were presented at the third annual meeting of this society at Calgary, in January, 1931, and at subsequent monthly meetings. This information is presented in an attempt better to define and describe the geologic formations, both surface and subsurface, and to clarify their nomenclature and correlation.

The geologic map which accompanies the symposium is likewise an attempt to assemble accurate information in so far as it is now available. No claim is made for finality in regard to it, but it is thought to be a nearer approach to the truth than anything heretofore published.

The symposium is offered as a tribute and memorial to the late Donaldson Bogart Dowling, in memory and appreciation of his outstanding contributions to the geology of southern Alberta.

Acknowledgment must be made at the outset to the oil companies and governmental bodies who have made this symposium possible by extending permission to the actual workers to publish the material assembled by them.

Few, if any, of the papers appear in the same form in which they were originally presented. During the discussions many points were criticized in great detail, and agreement was reached on such questionable points before the final draft of the papers was made. In view of this, the symposium may be regarded as the work of the Alberta Society of Petroleum Geologists as a whole, and as carrying the approval of this body. Credit is due not only to the authors, but also to the members of the Society who contributed to the discussions of the papers.

It is exceedingly gratifying to note the striking agreement on many stratigraphic details arrived at by different men working quite indepently of one another. Such agreement adds greatly to the value of the data presented in the symposium.

In addition to verbal discussions which were later incorporated in the papers, the symposium has been edited to insure uniformity of nomenclature and to harmonize conflicting statements in different papers touching on the same problems.

Editorial Committee, THEODORE A. LINK, *chairman*
J. S. IRWIN S. E. SLIPPER
DELMER L. POWERS ROBIN WILLIS

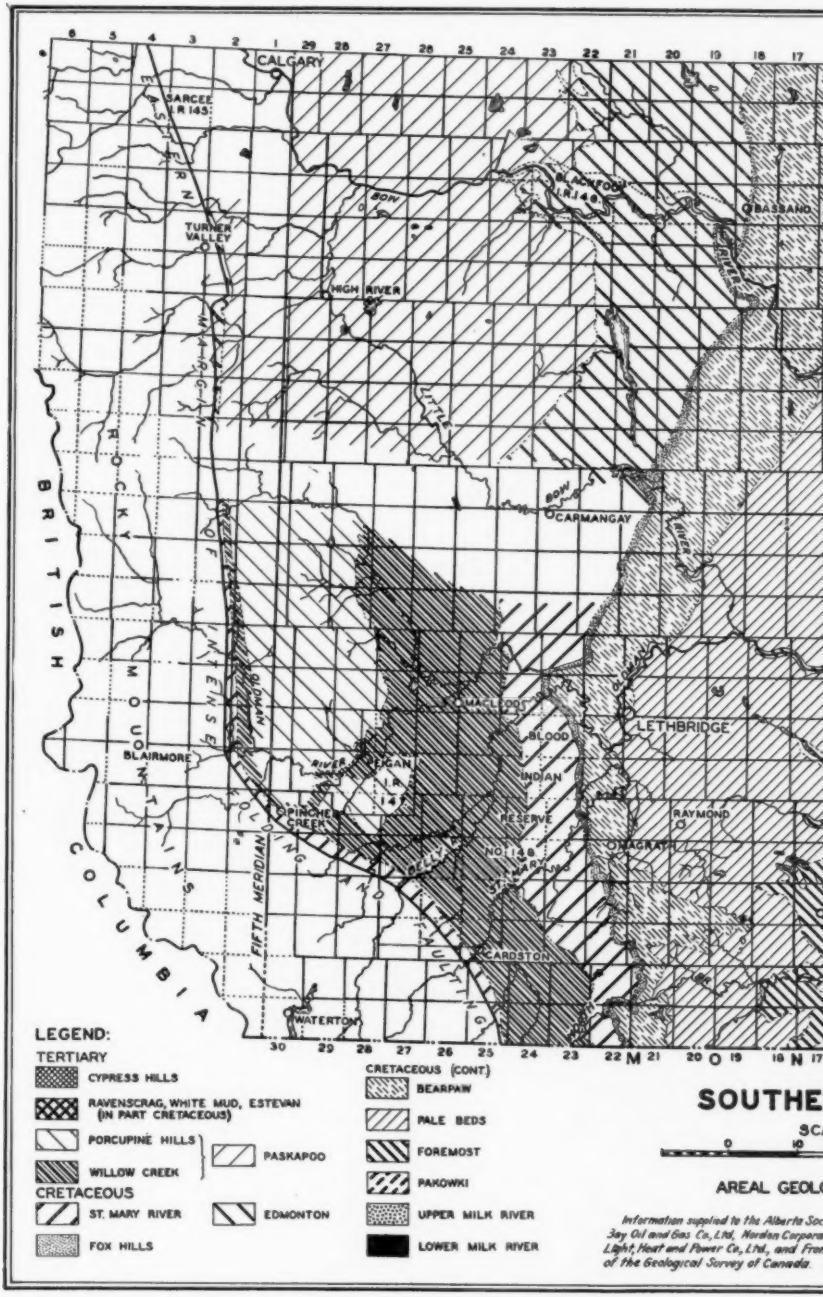
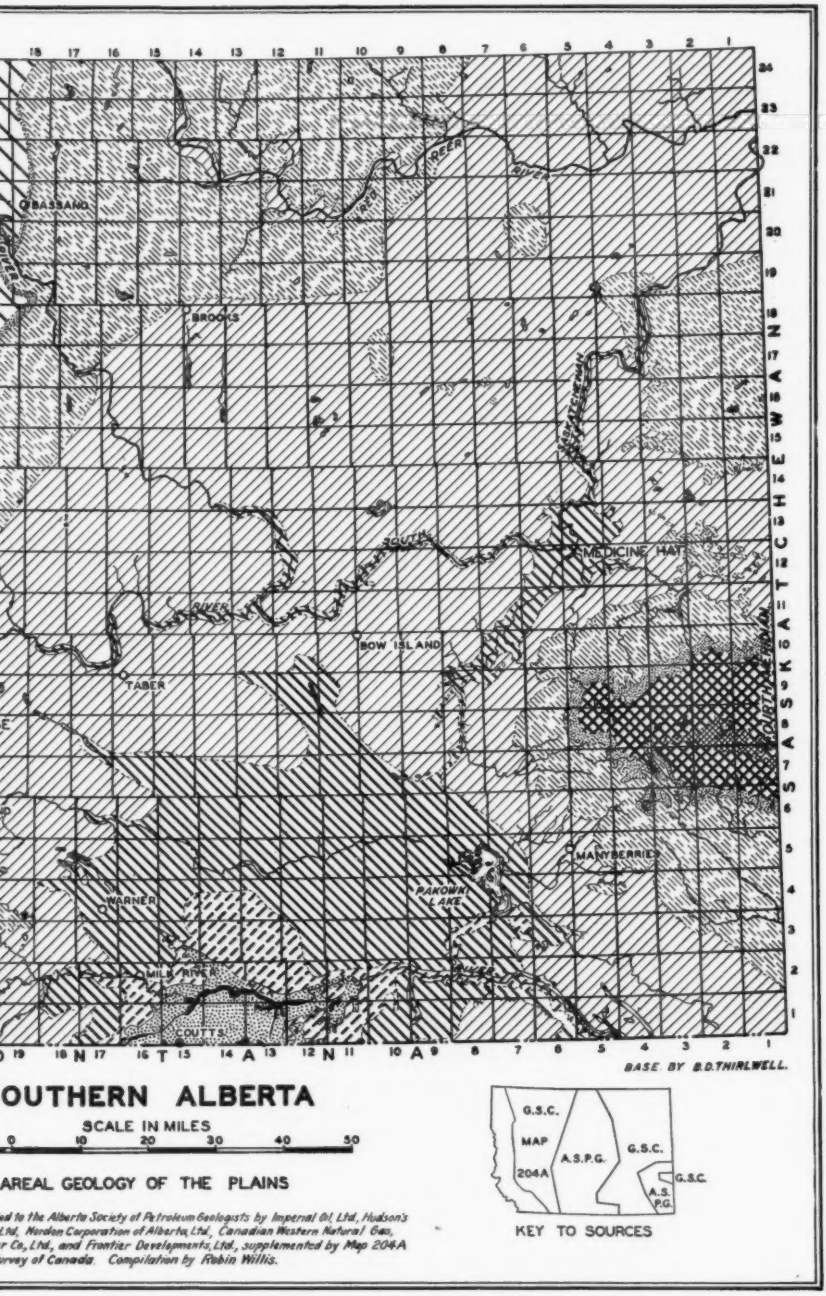


PLATE I—Geological map of plains of southern Alberta, compiled und



OUTHERN ALBERTA

SCALE IN MILES
0 10 20 30 40 50

AREAL GEOLOGY OF THE PLAINS

ed to the Alberta Society of Petroleum Geologists by Imperial Oil Ltd, Hudson's Ltd, Norden Corporation of Alberta Ltd, Canadian Western Natural Gas, r Co, Ltd, and Frontier Developments Ltd, supplemented by Map 204A urvey of Canada. Compilation by Robin Willis.

KEY TO SOURCES

compiled under auspices of Alberta Society of Petroleum Geologists.

STRATIGRAPHIC CORRELATION AND NOMENCLATURE IN PLAINS OF SOUTHERN ALBERTA[1]

J. S. IRWIN[2]
Calgary, Alberta

ABSTRACT

Correlation of the strata underlying the plains of southern Alberta with the better known formations of Montana is attempted. This is offered as justification for the nomenclature adopted in the symposium of which this paper is a part. More widespread approximate correlations including the greater part of the Rocky Mountain cordillera and geosyncline from New Mexico and Utah to Alberta are attempted, and a simplified nomenclature in accordance therewith is suggested for the plains of northern Montana and southern Alberta.

INTRODUCTION

This paper is a brief summary of stratigraphic correlation and nomenclature to accompany a group of papers on the stratigraphy of the plains of southern Alberta. Its principal purpose is to harmonize the accumulated stratigraphic data of southern Alberta with those of the adjacent areas in Montana which have been studied more closely and for a longer period, but it seems to the writer that the opportunity to emphasize the probable validity of more widespread correlations and resultant simplification of nomenclature may pardonably be embraced at this time. If one qualified observer had viewed all the formations within the Rocky Mountain cordillera and geosyncline from New Mexico and Utah to Alberta and had had all the information that we now have, it seems certain that there would have been no such multiplicity of formation names as now exists. The formations which are strikingly similar in general appearance, lithologic character, and fossil content, from New Mexico to Alberta, would conceivably have been given one name each and the fact that a lithologic unit varies somewhat in age from place to place as inferred from its included fossils, or that an age unit differs from one locality to another, in lithology, would have worried such an observer little, for he would have realized that very long periods of time are required for a strand line to advance many hundreds of miles,

[1]Presented before the Alberta Society of Petroleum Geologists, April 18, 1931. Manuscript received, May 18, 1931.

[2]Chief geologist, Parco Oil Company, Ltd.

and that continental or littoral conditions may exist in one area while elsewhere deep-water conditions prevail.

In accordance with this broader view and in the interest of simplicity and practical utility, the following table of formations is suggested for northern Montana and southern Alberta. The formation names used are selected on the basis of priority and seeming general acceptability, but the actual names used are relatively unimportant as compared with the principle involved. Local names for members or for local phases could be retained or supplied as found advisable.

SUCCESSION OF FORMATIONS IN NORTHERN MONTANA AND SOUTHERN ALBERTA

Adopted in Symposium		*Proposed Simplification*	
St. Mary River and Edmonton formations		Lance formation	
Fox Hills sandstone		Fox Hills sandstone	
Bearpaw shale		Bearpaw shale	
Belly River group: Pale beds and Foremost formation	Pierre group	Belly River group: Mesaverde formation	
Belly River group: Pakowki formation		Belly River group: Claggett formation	
Belly River group: Milk River formation		Belly River group: Eagle sandstone	
Colorado shale		Colorado shale	
Blackleaf member of Colorado shale		Dakota group (Lee)	
Blairmore formation			
Ellis formation		Sundance formation	
Madison limestone		Madison limestone	

It is probable that no such simplification of nomenclature as that suggested will be generally adopted, at least without reference to committees, but if this paper suggests the possibility and advisability of such procedure, it may be of some value.

DISCUSSION OF FORMATIONS

The correlation chart (Table I) shows the formations known to be present in the plains area of southern Alberta, and their equivalents in the adjoining plains of Montana.

Pre-Cretaceous.—There is little reason for argument concerning the nomenclature of the pre-Cretaceous formations. Accordingly, the highest Paleozoic limestone, known in southern Alberta only from its occurrence in the few deeper bore holes, is named the Madison, and the Jurassic beds which lie, so far as known, with slight angular discordance, on the eroded surface of the Madison are termed the Ellis formation. Fossils indicate that the Ellis is in part equivalent to the Sundance formation of southern Montana and Wyoming and the Fernie of the Alberta foothills.

TABLE I

GEOLOGIC FORMATIONS IN PLAINS OF SOUTHERN ALBERTA AND NORTHERN MONTANA

Age	*Series*	*Southern Plains of Alberta*			*Northern Montana East of Sweetgrass Arch*	*Northwestern Montana West of Sweetgrass Arch*
Upper Cretaceous	Montana	St. Mary River formation			Lance	St. Mary River formation
		Fox Hills sandstone			Fox Hills sandstone	Horsethief sandstone
		Bearpaw shale		Pierre group	Bearpaw shale	Bearpaw shale
		Belly River group: Pale beds			Judith River formation	Two Medicine formation
		Belly River group: Foremost formation				
		Belly River group: Pakowki formation			Claggett formation	
		Belly River group: Milk River formation	Upper		Eagle sandstone with Virgelle sandstone member at base	
			Lower			Virgelle sandstone
	Colorado	Colorado shale with Blackleaf sandy member in lower part. Lower part of Blackleaf is probably equivalent of Dakota		Dakota group (Lee) Upper Cretaceous	Colorado shale with Blackleaf sandy member in lower part. Lower part of Blackleaf is probably equivalent of Dakota	
Lower Cretaceous		Blairmore formation			Kootenai formation	Kootenai formation
		Disconformity ?				
Jurassic		Ellis formation			Ellis formation	Ellis formation
		Widespread unconformity				
Paleozoic		Madison limestone (Mississippian) and underlying formations				

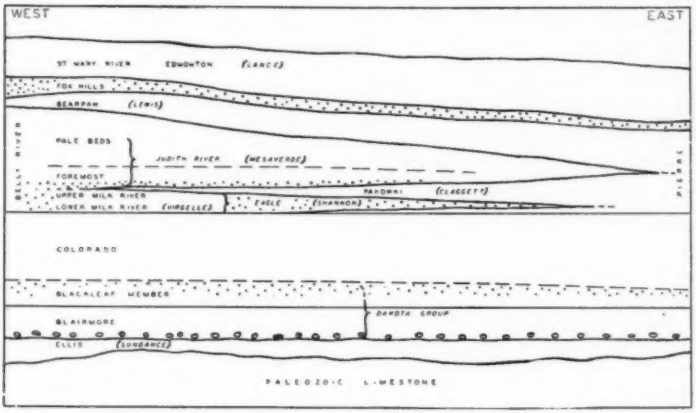


FIG. 1.—Diagrammatic composite section across Montana and southern Alberta, in part after Stebinger, *U. S. Geol. Survey Prof. Paper 90* (1927), p. 67.

Blairmore formation.—Information derived from the records of recently drilled wells has led certain contributors to the symposium to conclude that, in the southern plains of Alberta, all the strata included between the Ellis formation and the Colorado shale are correlative with the Blairmore formation of the Alberta foothills. As it is also possible that these strata are essentially the same as those which crop out in the Great Falls area in Montana and are there designated as Kootenai, it is concluded that the name "Kootenai" is improperly applied at Great Falls. The original correlation of the strata in question at Great Falls was made more or less tentatively with the type locality of "Kootenay" in Canada on the basis of fossil plants.

The plane of separation between the Upper Cretaceous and Lower Cretaceous systems is, on fossil plant evidence, generally regarded as being within the Blairmore formation.[1] Here also the evidence of the plants seems questionable. The base of the Blairmore formation is marked by a conglomerate bed which occurs in a large part of the Alberta foothills province and has now been recognized in deep wells on the plains by W. S. Yarwood and P. D. Moore. It seems to the writer more reasonable to suppose that the conglomerate marks the advent of the Upper Cretaceous (Dakota) sea. If this is true, the Blairmore is entirely Upper Cretaceous.

[1]Edward W. Berry with F. H. McLearn and S. S. Buckman, "Mesozoic Paleontology of the Blairmore Region, Alberta," *Geol. Survey of Canada Mus. Bull. 58* (1929), p. 31.

The situation is seemingly the same as that described by Lee[1] in Colorado, Wyoming, and Montana. On structural grounds Lee believed the widespread conglomerate which lies unconformably on the Morrison formation (Lower Cretaceous) from southern Colorado to Lewistown, Montana,

> to be the first sedimentary expression. . . .of the sea that invaded the interior of North America about the middle of the Cretaceous period.

In other words, as indicated on Plates 1 and 2 of his paper, he believed all the sediments from the post-Morrison conglomerate upward, to and including the Dakota or Muddy sand ("Upper sand"), to be Upper Cretaceous, and these he designated the Dakota group as typified at Bellvue, Colorado. Thus Lee correlated the Purgatoire formation of southern Colorado, the Cloverly formation of Wyoming, the Lakota sandstone and conglomerate of the Black Hills, and the Kootenai formation of the Lewistown and Great Falls areas in Montana. As previously mentioned, it is very probable that the Kootenai at Great Falls is Blairmore and that the Blairmore, together with some part of the overlying Blackleaf member, is the equivalent of Lee's Dakota group, of Upper Cretaceous age. It should be stated that

> the U. S. Geological Survey accepts Dakota Group for the section at Bellvue, Colorado, only with the understanding that if rocks of Comanche age should be found there they are to be excluded from the Dakota group.

Dakota sandstone.—The Dakota sandstone has not heretofore been definitely recognized in the plains region of southern Alberta and northern Montana. However, it is the opinion of several, including the writer, that the lower part of the Blackleaf member of the Colorado shale is the lithologic and homotaxic equivalent of the beach sand deposited in the encroaching sea which inaugurated the definitely marine condition of Upper Cretaceous time. If this interpretation is correct, the lower part of the Blackleaf member should be removed from the Colorado shale and should be named Dakota sand. References favoring the interpretation of the sands in the lower part of the Colorado shale as Dakota sand follow.

Lee[2] considers the Muddy sand of the Big Horn Basin, Wyoming, and its equivalent in southern Wyoming and Colorado, to be the "Upper

[1]Willis T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), p. 23 and Plates 1 and 2.

[2]Willis T. Lee, *op. cit.*, p. 23.

sand" member of the Dakota group rather than a sand member in the lower Colorado (Thermopolis) shale.

Collier[1] states that:

No marine fossils were found in the lower 400 feet of the section. . . ., and the great abundance of fossil wood present in places in it led the writer to believe that either the upper boundary of the Kootenai should be placed much higher in the stratigraphic column, or the lower 400 feet of the Colorado shale is equivalent to the Dakota sandstone. Should determinable fossil plants or other fossils be found in this part of the section, the problem might be solved. The plants might be expected to belong to the Lower Cretaceous flora of the Kootenai or the Upper Cretaceous flora of the Dakota.

Bauer and Robinson[2] interpret the lower sands of the Blackleaf sandy member in northern Montana as the homotaxic equivalent of the Dakota sandstone.

Colorado shale.—"Colorado shale" as a name for the marine strata lying between the Kootenai formation and the Eagle (Milk River) sandstone is firmly established in northern Montana and has now been adopted in Alberta. The use of the name Benton in Canada for the entire shale body between the Blairmore and the Belly River beds is so obviously an error that it should be discontinued. An excellent statement by Stebinger[3] to cover this point seems worthy of quotation.

The use of the name Benton shale for shale overlying the supposed Dakota in southern Alberta is also inadvisable, for no evidence afforded either by fossils or lithology is important enough to warrant the recognition of the Benton and Niobrara divisions of the Colorado. The simple expedient of applying the term Colorado shale to strata in northern Montana, which include both Benton and Niobrara, has long been in use.

Later work by Collier[4] led him to make the following observations.

The upper 500 feet of the Colorado of the Sweetgrass arch can be definitely correlated with the Niobrara formation by the contained fossils, though the distinctive light-yellow color characteristic of the Niobrara of Wyoming and southeastern Montana is lacking here. Probably the next lower 400 feet can be correlated with the Carlile and Frontier formations, and the underlying 350 feet, containing many fish remains, a few invertebrates, and some shale

[1]Arthur J. Collier, "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," *U. S. Geol. Survey Bull. 812-B* (1929), p. 70.

[2]C. Max Bauer and Ernest Guy Robinson, "Comparative Stratigraphy in Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 2 (March-April, 1923), pp. 169-71.

[3]Eugene Stebinger, "Anticlines in the Blackfeet Indian Reservation, Montana," *U. S. Geol. Survey Bull. 641* (1916), p. 291.

[4]Arthur J. Collier, *op. cit.*, p. 72.

resembling Mowry shale, can be correlated with the Mowry and Thermopolis shales of Wyoming. The lower part of the beds here included in the Colorado shale, in which no fossils other than wood have been found, may possibly be the equivalent of the Dakota sandstone.

Present knowledge is probably insufficient to permit subdivision of the Colorado shale in the plains region of Alberta, but later it may be possible. It should also be stated that in southern Montana, Wyoming, and Colorado, strata of Montana age below the Eagle (Milk River) sandstone, or its equivalent, attain considerable thickness. Whenever and wherever certain upper parts of the so-called Colorado shale in Alberta shall be found to contain fossils which are conclusively diagnostic of its Montana age, those parts should either be named Pierre shale or given a new name recognizing their Pierre age.

Milk River formation.—As explained in one of the papers comprising this symposium, Stanton in 1905 proved that the Eagle sandstone of Montana is continuous and identical with beds which Dowling several years later termed the Milk River formation. Under the circumstances there was no justification for the introduction of the name "Milk River," but the usage is so firmly established that it probably would be difficult to uproot.

The lower massive member of the Milk River formation, known as the lower Milk River sandstone, is the equivalent of the Virgelle sandstone member of the Eagle sandstone on the east side of the Sweetgrass arch and of the Virgelle sandstone (a formation) on the west side of the Sweetgrass arch.

The upper Milk River formation is the equivalent of the upper Eagle sandstone in Montana, east of the Sweetgrass arch, and of the lower part of the Two Medicine formation west of the Sweetgrass arch.

The Eagle sandstone is believed to be the homotaxic equivalent of the Shannon sandstone[1] of Wyoming and is similar in stratigraphic position to the Hygiene sandstone of Colorado.

Pakowki formation.—The Pakowki formation, composed of marine shales and sandstones, was so named by Dowling in 1915, but Stanton and Hatcher had, in 1905, shown that these beds were to be correlated with the Claggett formation of Montana. This correlation is universally accepted; however, the term "Pakowki" seems firmly established in Canada.

The Pakowki, as a shale, is not recognized on the west side of the Sweetgrass arch, south of the International Boundary, although Stanton

[1]C. Max Bauer and Ernest Guy Robinson, *op. cit.*, p. 163.

recognized a Claggett-Fox Hills marine fauna in the sandstone about 200 feet above the base of the Two Medicine formation in this area which indicates a brief incursion of the marine waters of the Claggett (Pakowki) sea.

Foremost formation. Pale beds.—The Foremost formation and the Pale beds are correlative with all but the lower 200 or 300 feet of the Two Medicine formation on the west side of the Sweetgrass arch and with the Judith River formation on the east side. The Judith River formation in turn has been traced into Wyoming, where its base is found to be identical with the Parkman sandstone, the base of the Mesaverde formation in eastern Wyoming.[1] The Pale beds and the Foremost formation are therefore the approximate equivalent of the Mesaverde formation of Wyoming and Colorado. In the light of present knowledge the names, Foremost, Pale beds, and Two Medicine are unnecessary and should be eliminated in favor of Judith River. In turn, and for the same reason, Judith River might be supplanted by the name Mesaverde. The Pale beds and the Foremost formation could be recognized as members.

The Foremost formation and the Pale beds are difficult of separation in many areas and separate mapping is not yet everywhere possible, as indicated on the map (Plate 1). For this reason the appropriateness of ranking them as distinct formations may be open to question. However, in support of their differentiation, it may be said that from earliest times observers have noticed a general dissimilarity between the two formations, although the exact plane of separation may not be apparent in places. The same statement may be applied to these formations as revealed by drill cuttings.

Belly River series.—The Belly River series as defined by Dawson[2] comprises all the strata between his "Lower dark shales" and his "Pierre shales." According to Stebinger,[3] and, as is now well known to all workers in the area,

> the Colorado shale. . . . can be traced directly into an area near the international boundary mapped by Dawson as Lower dark shales. The Bearpaw shale can be traced with equal facility into the shale mapped by Dawson as Pierre, and the Horsethief sandstone into Dawson's Fox Hills sandstone.

[1]K. C. Heald, "Oil-Bearing Horizons of Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (March-April, 1921), p. 204.

[2]G. M. Dawson, "Report on the Country in the Vicinity of the Bow and Belly Rivers," *Geol. Survey of Canada Rept. of Progress for 1882-1884*, p. 112-c.

[3]Eugene Stebinger, *op. cit.*

It is thus evident that the Belly River series includes all the strata between the Colorado shale and the Bearpaw shale, namely, the Milk River formation, Pakowki shale, Foremost formation, Pale beds, and their Montana equivalents as indicated in the table of formations.

Williams and Dyer[1] limit the Belly River series to the continental beds lying between the Pakowki and the Bearpaw for the reason that

> Dawson believed the dark shale in Milk River Valley above and below Pakowki coulee to be equivalent to the dark Colorado shales exposed on the sides of the Sweetgrass hills.

This shale is now known to be the Pakowki (Claggett) shale, but the error does not affect Dawson's original definition of the Belly River series as immediately overlying the Lower dark shales (Colorado shale). The fact that a wedge of marine shale (Pakowki) fingers in between continental beds in a part of the area, likewise can not properly alter Dawson's intention. The practice of Dowling[2] and Dawson is therefore followed and the Belly River series is made to include the Milk River, Pakowki, and Foremost formations, and the Pale beds.

Bearpaw shale.—In those western areas of both Alberta and Montana where the continental and littoral strata of the Belly River series interfinger with marine shales, the highest marine shale body is known as the Bearpaw shale. This shale is, with little doubt, the counterpart of the Lewis shale of Wyoming. Dawson properly recognized the age of the Bearpaw shales when he termed them "Pierre shales."

Pierre series.—The Belly River series and the overlying Bearpaw shale constitute all the strata of Pierre age in the region. The continental and littoral deposits which lend lithologic diversity to the Pierre series in the piedmont and western plains areas become increasingly marine in character and decrease in thickness eastward until the entire series becomes a marine shale unit.

Fox Hills sandstone.—The Fox Hills sandstone marks the final recession of the Montana sea over the immense area included in southern Alberta, the Dakotas, Wyoming, Colorado, and, probably, New Mexico. The remarkable extent of this comparatively thin, generally marine sandstone stratum, together with its uniform lithologic character and fossil content, makes it perhaps the best horizon marker in the Cretaceous system.

[1]M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930), p. 16.

[2]D. B. Dowling, *Geol. Survey of Canada Sum. Rept.* (1915), map opp. p. 104.

"Fox Hills" is the name of the formation in general use throughout the area of its occurrence in both Canada and the United States. The name "Horsethief" in northwestern Montana, and possibly "Lennep" in central Montana, are local names which now seem unnecessary. The Colgate sandstone of southeastern Montana and the Milliken sandstone of the Denver basin in Colorado are locally named members of the Fox Hills sandstone in every way similar to the Fox Hills of southern Alberta.

St. Mary River formation.—The St. Mary River formation comprises all the continental deposits between the marine and brackish-water Fox Hills sandstone below and the fresh-water Willow Creek formation above. The name "St. Mary River" is in use in northwestern Montana west of the Sweetgrass arch and in southern Alberta south of Little Bow River. North of Little Bow River in Alberta, and east of the Sweetgrass arch in Montana, the approximately equivalent continental, coal-bearing strata which rest with transitional contact on the Fox Hills sandstone, or on the Bearpaw shale where the Fox Hills is locally absent, are named Edmonton and Lance respectively. Farther south in Wyoming and Colorado the essentially equivalent rocks are known as the Laramie formation or by various local names. "Lance" seems to be a satisfactory term to apply to these strata throughout their extent. The St. Mary River (Lance) formation is the highest formation considered in the symposium.

CONCLUSIONS

The Rocky Mountain cordillera and geosyncline extending from New Mexico and Utah to Alberta are, geographically and geologically, not large, yet geologic formations which are, in the light of accumulated evidence, the same or practically the same, are known at various localities by different names. This situation is the natural outcome of the exigencies of the earlier investigations wherein restricted areas were studied by different individuals. The perspective which personal observation of the entire area, together with the recorded observations of others, affords, seems to require the simplification of regional nomenclature herein suggested.

The basis of the long-distance correlations is primarily lithologic; no other basis is generally practical. Admittedly the lithologic units differ in age from one locality to another by the length of time required for the advance or retreat of the strand line across the intervening space, but practical considerations require the naming of the tangible rather than the intangible. Is it not more useful and scarcely less scientific,

for example, to state, if indicated by paleontological evidence, that the Fox Hills sandstone of Colorado is older than the same sandstone in Alberta, or that the St. Mary River formation west of the Sweetgrass arch in Montana and Alberta is, in part, older than its lithologic and positional equivalent, the Lance formation east of the arch, but nevertheless in each case where more than one name is in use, to retain only one,—preferably the older?

The local nomenclature adopted and set forth in Table I is justified by correlation of the formations of the plains of Alberta with those of the adjoining part of Montana and by the information presented in the symposium.

PALEOZOIC OF SOUTHERN PLAINS OF ALBERTA[1]

P. D. MOORE[2]
Turner Valley, Alberta

ABSTRACT

Deep drilling in the exploration for oil during the past few years has revealed the northern Montana Paleozoic section in the plains of southern Alberta. Records of the Paleozoic of the deep wells in the Kevin-Sunburst field, especially the Adams No. 1, on the Potlatch lease, are compared with those of southern Alberta. Distance from exposures and type localities impose difficulties on correlations, because great lithologic changes occur in the intervals. Most notable are those strata assigned to the Three Forks, composed mostly of a thick massive anhydrite zone. The thin widespread sheet of black shale is chosen as the upper member of the Three Forks formation.

INTRODUCTION

The purpose of this discussion is to describe the general characteristics of the Paleozoic formations underlying the plains of southern Alberta. Data have been obtained entirely from rock cuttings of the deeper wells drilled in the area (Fig. 1). The information from all of the wells which have been drilled into the Paleozoïc has been assembled on the accompanying chart (Fig. 2).

The Paleozoic formations do not crop out at any place in the plains of southern Alberta, but there are outcrops of Madison limestone at the borders of the intrusive cores of the Sweetgrass Hills in northern Montana. A good partial section is exposed on the northeast flank of East Butte.

Although parts of the formations have been revealed as differing from well to well, the upper part of the Madison limestone is remarkably uniform.

The upper contact zone of the Madison limestone has been considered as the reservoir of the oil in the Kevin-Sunburst field, and, as drilling was extended into Alberta, it was hoped that these same conditions would prevail. To date the results of drilling in the Paleozoic of the plains of southern Alberta have been entirely without commercial re-

[1]Presented before the Alberta Society of Petroleum Geologists, April 18, 1931. Manuscript received May 18, 1931. Published by permission of O. B. Hopkins, 56 Church Street, Toronto, Canada.

[2]Geologist, Royalite Oil Company, Ltd.

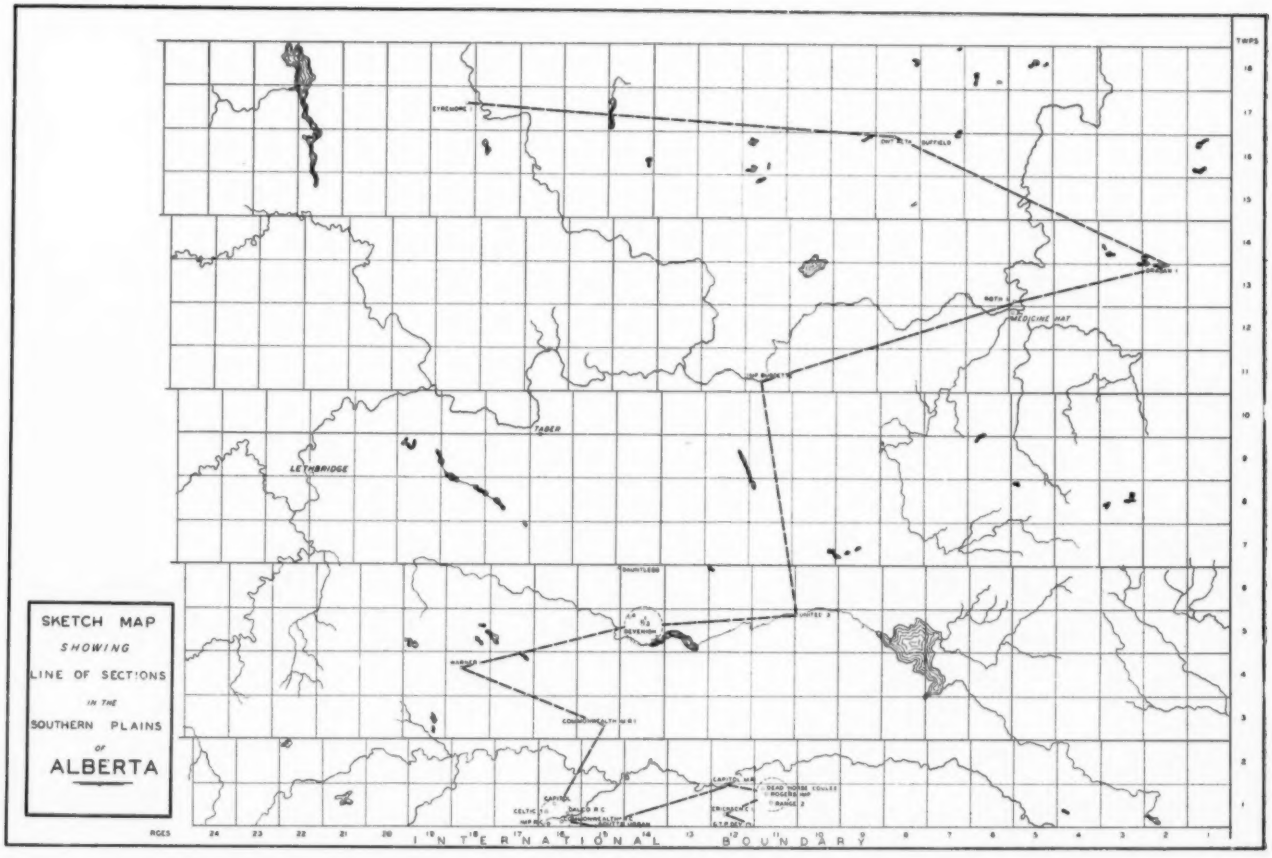


FIG. 1.—Index map showing location of bore-holes discussed in this paper. Each township or range, approximately 6 miles square.

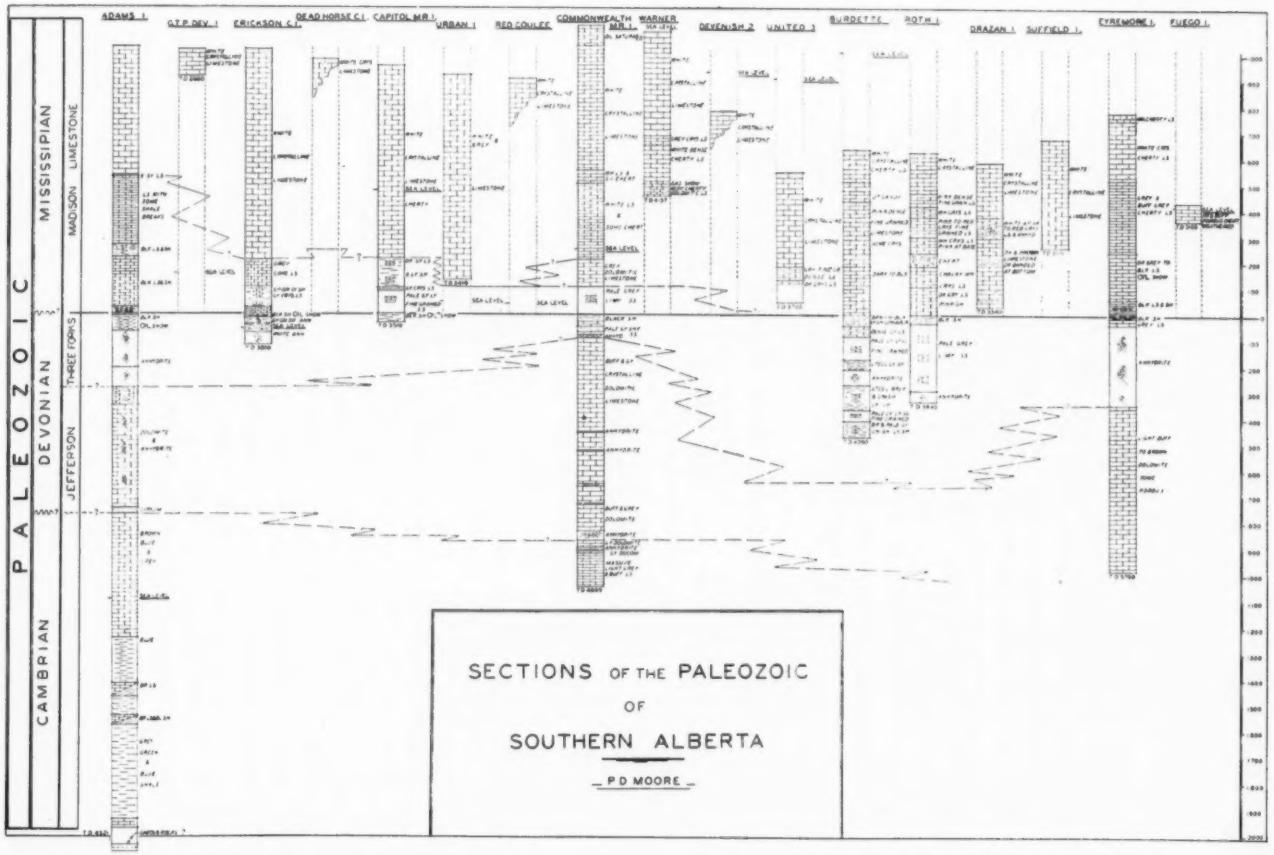


FIG. 2.—Columnar sections of Paleozoic strata encountered in drill-holes shown in Figure 1. The "black shale" is a reference horizon or datum.

ward. Many of the deeper wells have either only touched the top of the Madison or drilled into it merely 100 or 200 feet.

GENERAL STATEMENTS

As the drilling into the Paleozoic in southern Alberta has revealed little that could be considered new regarding the lithology of the formations, no new names are proposed. Likewise very little paleontologic information has been found. Hence the discussion is constantly referred to the more detailed studies made of these formations where they crop out along the rims of the mountain areas and uplifts of Montana and northern Wyoming, and to the studies of the drill cuttings from the deep wells in the Kevin-Sunburst field.

The type locality of all the Paleozoic formations of Montana is in the vicinity of Three Forks, but toward the International Boundary great lithologic changes occur in all formations except the Madison limestone.

In the general region of Montana and Wyoming there are two pronounced unconformities that must be considered. The first is at the base of, or may include parts of, the Pennsylvanian rocks on older formations, and the other is at the base of the Jurassic on older formations. In the restricted area of southern Alberta and adjacent Montana only the one unconformity at the base of the Jurassic is present. This hiatus is of the first order of magnitude, as middle Mesozoic formations lie on middle Paleozoic. Farther north and east this unconformity merges with that at the base of the Cretaceous, as shown by Link.[1]

The effects and character of the bevelling and its depth in the Madison limestone are considered by the writer in this discussion. Farther afield from the restricted area of the southern plains, the true nature of the magnitude of the pre-Jurassic bevelling of the Paleozoic is more fully understood. At the Manitoba escarpment the Lower Cretaceous lies on Upper Devonian. At the north, on Clearwater River and on the Mackenzie and its tributaries, Cretaceous lies on Upper Devonian.[2] Northwest of the southern plains on the Rocky Mountain front, and, as is known from drilling, in the foothills along their eastern border, the Jurassic lies respectively on Mississippian, Pennsylvanian, and Triassic.

In the discussion of this bevelling of the Madison, northward from the International Boundary, reference is made to the results of drilling

[1] Theodore A. Link, "Alberta Syncline, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 491-507.

[2] Theodore A. Link, personal communication.

beneath the Mesozoic mantle, at places beyond the plains of southern Alberta, in order more fully to interpret the conditions there.

MADISON LIMESTONE

The Madison is almost entirely composed of limestone, and is very uniform in character. In the lowest part it is thin-bedded, shaly, and in some places contains 20-30 feet of fine-grained, pale gray, limy sandstone. This lower clastic phase grades upward into purer limestones, which in the upper and greater part are massive, white, and crystalline, with some dolomitic and cherty limestones. The upper massive part shows practically no bedding and little jointing in the cores which have been examined. The thicker chert zones seem widespread, as is shown in the columnar sections. The upper 500 feet of the formation is generally much more coarsely crystalline and more nearly white. The lower part is finer-grained, dense, and of darker color. The whole formation is generally hard and resistant, and drilling progress in it is ordinarily slow. There are many fossil zones; the types commonly seen in cores are brachiopods and fenestellid bryozoans. In the bryozoan beds the fossils are generally so plentiful that they simulate reef conditions. Many of these zones are almost pure dolomite and the fossils are casts, as shown in Figure 3. The bryozoan beds are, as a rule, only a few feet thick. The fauna of the Madison is fully discussed by Girty.[1] In discussing this formation as exposed in the Yellowstone National Park and vicinity, Girty concludes that its age is nearly or quite the same as the Kinderhook of the typical Mississippi Valley section.

The only variation from the general white crystalline character of the upper part is a red and pink limestone and chert phase that is revealed in the Imperial-Burdette well No. 1, Roth No. 1, and Drazan No. 1, in the vicinity of the city of Medicine Hat. This zone has sharp upper and lower contacts and ranges in thickness from 250 feet in Imperial-Burdette No. 1, to 370 feet in Roth No. 1, and to 85 feet in Drazan No. 1. Thin phases, ranging from a few to 20 feet in thickness in this pink or red zone, are entirely chert. This development, of the otherwise white, crystalline massive limestone part of the Madison, is exceedingly conspicuous in the logs of these wells, and it is strange that it does not continue farther than these three adjacent holes.

It is also noticeable that there is a prominent thinning of the lower part of the Madison, which is of darker color, and consists of more im-

[1]George H. Girty, "Geology of the Yellowstone National Park," *U. S. Geol. Survey Monogr. 32*, Part II (1899), pp. 483-96.

FIG. 3.—Core of bryozoan limestone taken from Dauntless well No. 1. Depth, 3,288 feet. Top of Madison, 3,225 feet. Natural size. Scale in inches.

pure limestones, some of which are clastics, as is shown in the Capitol well No. 1-A, and the Commonwealth-Milk River No. 1, where the lowest member is pale gray, fine- and uniform-grained, limy sandstone. This clastic and more impure limestone phase of the basal Madison gradually disappears northward in the line of sections so that in the short space from the Commonwealth-Milk River well No. 1 to the Burdette No. 1, pure limestones (although dark in color) rest on the datum bed, the black fissile fossiliferous oil shale, which, in this discussion, is regarded as the top of the Three Forks formation. The reason which the writer suggests for this arrangement can better be discussed in the section devoted to the possible environment of the Three Forks and immediately succeeding sedimentation of the lower Madison.

The Paleozoic log of the Fuego Oils No. 1 is added to the line of sections merely to show the undoubted deeper bevelling into the Madison limestone north of the area under discussion. The well is located about 50 miles north of the Eyremore No. 1, and those wells in the vicinity of Medicine Hat, including the Suffield, Drazan, and Roth. In

Fuego No. 1, only 65 feet were penetrated beneath the top of the Paleozoic. All of the formation penetrated was weathered and fossiliferous chert, as shown in Figure 4. Well preserved fossils obtained from the

FIG. 4.—Leached and porous fragments of chert from Fuego well No. 1. Blown from well by gas. Depth, 3,130 feet. Top of Madison, 3,100 feet.

cuttings were submitted to P. S. Warren, of the University of Alberta, who recognized a *Camarotoechia*, which he assigns definitely to the lowest Mississippian of the Rocky Mountain sections near Banff, Alberta, at which place he has made detailed studies of these beds.[1]

Although the writer believes he has used discretion in the placement of the partial sections of these wells, touching or penetrating only a few

[1]P. S. Warren, "Banff Area, Alberta," *Geol. Survey of Canada Mem. 153* (1927).

to several hundred feet into the Madison, he is not entirely satisfied with the correlations which are, perforce, needed. Further, because the whole aspect of the problem of bevelling is compressed into one chart, a cross-sectional aspect along various lines is not shown nor is it believed feasible with the data at hand. However, due consideration has been given to regional structure as much as possible, as a help in interpreting the position of partial sections. Therefore it is believed that the logs, as plotted, are not greatly in error.

In the many samples of drill cuttings of Madison limestone which the writer has had at his disposal, he has never noticed any anhydrite or gypsum, excepting in the core of the Drazan well No. 1. It is believed that this occurrence represents the filling of solution cavities and is not of primary origin. There are several places in the foothills of central Alberta where it is definitely believed that infiltrating surface waters from the outcropping intake have filled porous dolomitic zones. Cores of these zones show that cavities, some of considerable size, with irregular walls, are completely filled with anhydrite, and that bedding in the anhydrite is not present. This occurrence is decidedly different from those zones of anhydrite in the formation here regarded as the Three Forks.

THREE FORKS

The Three Forks formation, as well as the Madison, has recently been described from the field and drill cuttings by several authors[1] discussing the Kevin-Sunburst field.

The great difficulty in assignment of beds to any age below the Madison, in Kevin as well as in southern Alberta, is that these localities are far from the type sections. Unknown and gradual changes occur in this interval. However, Collier[1] reports paleontologic evidence showing that the beds below the Madison in the Kevin-Sunburst field are Devonian.

HIGHEST CONTACT BED OF THREE FORKS

In the earlier reports on the Kevin-Sunburst field much uncertainty existed regarding the exact base of the Madison. Such a view is also

[1] W. F. Howell, "Kevin-Sunburst Field, Toole County, Montana," *Structure of Typical American Oil Fields*, Vol. 2 (Amer. Assoc. Petrol. Geol., 1929), pp. 245-68.
T. B. Romine, "Oil Fields and Structure of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), pp. 779-97.
A. J. Collier, "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," *U. S. Geol. Survey Bull. 812-B* (1929).

[2] *Op. cit.*, pp. 63-64.

stated by Collier,[1] although he recognized that the lower one-third was shaly and should be correlated with the Lodgepole limestone[2] of the Little Rocky Mountains.

So far as the writer is aware, Roy Lebkicher[3] was the first to recognize that the black fissile shale (a lean oil shale) 10-50 feet thick, was the widespread upper contact bed of the Devonian. Romine[4] did not choose this bed as the upper limit of the Devonian, but the fine-grained, pale gray, limy sandstone, 30 feet thick, lying above the black fissile shale.

Perry[5] summarizes the reasons for the choice of this black, fissile shale as the upper member of the Devonian. The first well to reveal the presence of this bed in southern Alberta was Imperial Oil's Burdette No. 1, a deep test in the center of the Bow Island gas field. The well was drilled by the rotary process and a complete core was obtained from this bed. Fossils, chiefly *Lingula spatulata*, were plentiful throughout the core obtained. Collections of this core were submitted to E. M. Kindle, of the Geological Survey of Canada, and the foregoing is his determination. This species is a typical highest Devonian form having an almost world-wide distribution. Although the writer has no inflexible views or definite data to prove that this bed of petroliferous shale is actually the top member of the Devonian, he believes that its choice by Lebkicher and Perry is reasonable, as it has been shown to have a widespread distribution. Lebkicher[6] reports this bed or zone at several localities in northern Montana, from which he has made fossil collections. The writer believes that it is this bed which was encountered in the Alberta Pacific's Duvernay well[7] in the drilling of the top part of the Paleozoic in northern Alberta at depths ranging from 2,230 to 2,280 feet. The top of the Paleozoic was here struck at 2,070 feet. P. S. Warren, of the University of Alberta, identified *Lingula spatulata* from this bed in core samples from this well.

[1]*Op. cit.*, p. 64.

[2]A. J. Collier and S. H. Cathcart, "Possibility of Finding Oil in Laccolithic Domes South of the Little Rocky Mountains, Montana," *U. S. Geol. Survey Bull. 736* (1923), p. 173.

[3]Geologist, The California Company, personal communications.

[4]*Op. cit.*, p. 790.

[5]E. S. Perry, "The Kevin-Sunburst and other Oil and Gas Fields of the Sweetgrass Arch," *Montana State Bur. of Mines and Metallurgy Mem. 1* (1928), pp. 5-6.

[6]Personal communications.

[7]Location of this well: north bank of Saskatchewan River, Sec. 34, T. 55, R. 12, W. of 4th Mer., Alberta.

Except the Burdette No. 1 and Fuego No. 1, all wells shown on the chart (Fig. 2) were drilled with cable tools, and, as the rock cuttings are fine, no fossils were observed. In the complete suites of samples of rock cuttings which are available from the wells shown on the chart (Fig. 2), the writer can not too strongly emphasize the conspicuousness and the almost lithological identity of this black, fissile shale. It is, therefore, believed that it furnishes a reliable datum in the consideration of the upper Paleozoic of the area. There is, therefore, good evidence that an unconformity, or perhaps a disconformity, exists at the base of the Madison. The great lithological similarity of the black shale to the Chattanooga or New Albany shale of the central Mississippi Valley region, together with the paleontologic data at hand, suggests equivalency or near equivalency in age. The writer is fully aware, in assigning an Upper Devonian age to this bed, that the age (whether Devonian or Mississippian) of the Chattanooga shale, and its supposed homotaxial equivalents throughout the Mississippi Valley region, is and has been very much in dispute.

The black shale appears prominently in all the logs of five deeper wells in southern Alberta. These are spaced apart, as shown on the location plan (Fig. 1), from the International Boundary for more than 100 miles northward. Beneath the black shale in the Adams well No. 1 (Potlatch lease in the Kevin-Sunburst field), there occurs about 300 feet of very pure, massive, compact, pale gray anhydrite. The Erickson Coulee well No. 1 penetrated only 30 feet into what seems to be this massive zone of anhydrite beneath the black shale. However, the beds immediately beneath the black shale and above the anhydrite are gray and green shale with stringers of anhydrite, with one thin bed of pale gray, fine-grained, limy sandstone which is typical of this zone in other logs. Curiously, the farthest north well log shown on the section, the Eyremore No. 1, is in a general way almost a duplicate of the Adams No. 1 log. However, immediately beneath the black shale are 20 feet of hard, dense, gray limestone. This lies on a massive 310-foot zone of pure, pale gray anhydrite. Immediately overlying the black shale is 15 feet of hard, dense, gray limestone which is very glauconitic, the grains of glauconite being one millimeter and less in diameter. This is another item bearing on the placement of an unconformity at the top of the black shale and also the systemic boundary at that point. Goldman's[1] oft-cited study of the occurrence of glauconite supports this view.

[1] M. I. Goldman, *U. S. Geol. Survey Prof. Paper 129* (1921), pp. 1-22; "Basal Glauconite and Phosphate Beds," *Science, New Ser.*, Vol. 56 (1922), pp. 171-73.

POTLATCH ANHYDRITE (THREE FORKS ?)

As there is no evidence to show that the black shale should be separated from the Three Forks, it is here regarded as the top member of this division, which Perry[1] has named the "Potlatch anhydrite."

As stated previously, the logs farthest apart are practically duplicates below the black shale. The three intervening deeper holes, the Commonwealth-Milk River No. 1, Burdette No. 1, and Roth No. 1, reveal the true nature of the manner of deposition of these thick lenses of anhydrite. The Commonwealth log is especially noteworthy, as only five thin zones of anhydrite occur throughout the thickness penetrated. The thickest of these is about 8 feet, the others ranging from 2 to 5 feet. Only about 40 feet of anhydrite was penetrated in Burdette No. 1. This was a pure zone, as analysis of cores at the University of Alberta showed 99 per cent calcium sulphate. The Burdette well No. 1 and Roth No. 1 showed only pale gray, fine-grained, limy sandstones and gray and greenish, limy, splintery shales in the position of the anhydrite zone of the other two wells. The Commonwealth log showed this zone to be massive, predominantly buff and some gray, finely crystalline, very dolomitic limestone or almost pure dolomite down to the last anhydrite zone. Very detailed samples were obtained from this well.

Therefore, if Three Forks time is entirely represented by the Potlatch anhydrite deposition to and including the overlying black shale, it is extremely difficult to choose the boundary in the Commonwealth well. The writer offers the suggestion shown on the chart.

Regarding the age and stratigraphic position of the Potlatch anhydrite, Perry[2] states that

> the presence of anhydrite and gypsum at the same geological horizon is reported from a drill hole close to the town of Agawam, Montana, 50 miles southwest of the Kevin field. This indicates that the formation is quite extensive. *However, such a formation of anhydrite and gypsum below the Madison limestone has not been found in a similar stratigraphic position elsewhere in Montana, and it seems probable that its presence is confined to the area of the Sweetgrass arch. Search has been made for the formation south of Great Falls, where rocks below the Mississippian formation are found at the surface.* (Italics are the writer's.)

Therefore, although this formation may prove still more widespread than already demonstrated, deposition seems to have been in isolated embayments or arms of a bittern sea, evidently with low bordering land. Down-warping of the region, with consequent freshening or dilution of

[1] *Op. cit.*, p. 6.

[2] *Idem.*

the anhydrite depositing seas, flushed well-weathered soils into the basin. In this manner the widespread thin sheet of black shale which ends Devonian time may have been deposited.

The writer can not agree with the suggestion of Collier[1] that this anhydrite zone is a product of alteration of limestone. Regarding the age of the anhydrite formation, Perry[2] suggests that it seems best to "classify . . . [it as] about equivalent to the Jefferson formation." Romine,[3] however, following Lebkicher, places it definitely in the Three Forks. The writer favors the latter opinion.

JEFFERSON FORMATION

Unless drilling in northern Montana has furnished paleontologic data bearing on differentiation of the Jefferson from the underlying formations in the Adams well No. 1, the writer believes that such a limitation of the Jefferson must necessarily rest on general characteristics of that formation farther afield. Roy Lebkicher, in a letter[4] to the writer, gives the following description of the Jefferson in the type locality near Three Forks, Montana.

> The Jefferson is there about 500 feet thick and consists of smoky, or chocolate-brown, granular dolomite, much of it having a peculiar brecciated appearance and weathering with a rough, pitted gritty surface. The beds of the characteristic rock are separated by thin beds of lighter-colored, denser limestone or shaly limestone, giving the formation the appearance of heavy masonry. On fresh fracture, the rock has a glistening appearance, in some instances resinous; and it is further distinguished by a strong, peculiar, fetid odor which it emits when struck with a hammer. The Jefferson maintains a fairly uniform thickness of about 500 feet in the western part of the state, but it thins out to the east and disappears to the southwest in Wyoming.

About 500 feet of dolomitic limestones below the anhydrite zone in the Adams No. 1 log are considered by Lebkicher and Romine to be typically Jefferson. Descriptive logs of Adams No. 1 by Lebkicher and John G. Bartram[5] substantiate the foregoing description of the Jefferson.

In the Commonwealth-Milk River log, all beds below the highest anhydrite down to the basal anhydrite zone, correspond exceedingly closely with the foregoing description, and the writer can suggest no better

[1] *Op. cit.*

[2] *Op. cit.*, p. 6.

[3] *Op. cit.*, pp. 790-91.

[4] Personal communication, November 18, 1928.

[5] Geologist, the Midwest Refining Company, Denver, Colorado. Personal communication.

correlation than this, which indicates that these strata are all Jefferson. The same is true of all beds below the anhydrite zone in the Eyremore No. 1 log.

The Jefferson contains a small but distinctive fauna which has been discussed by E. M. Kindle.[1]

The few thin anhydrite zones shown in the Commonwealth log may be of primary origin, but there is a strong possibility that they are dolomitic cavities filled by circulating water. A heavy flow of a very concentrated brine was struck in the Eyremore well in a porous dolomite 50 feet from the top of this formation, or 1,158 feet below the top of the Madison.

PRE-JEFFERSON STRATA

In southern Alberta only the Commonwealth well No. 1 has penetrated beds that are possibly older than Jefferson. These are about 180 feet of strata that lie below the basal anhydrite zone. It is noteworthy that they are pure limestones, buff and buff-brown in color, crystalline, but not dolomitic. This zone is very uniform in character.

Romine,[2] quoting Lebkicher regarding the Adams No. 1 log, states that the lower 1,400 feet of strata below those beds assigned to the Jefferson are believed to be Middle or Lower Cambrian, and it is this correlation which the writer has chosen in preparing the chart. This assignment of age is based on the fact that the Ordovician, which is represented by the Bighorn dolomite of the Big Horn Mountains of Wyoming, is not known to extend westward beyond a north-south line crossing the central part of Montana.

The igneous rocks reported from the bottom of the Adams well No. 1 are questioned by Bartram,[3] who states his belief that they are probably surface boulders placed in the well to straighten the hole. This is further substantiated by Perry,[4] who states that

> thin-sections of the cuttings. . . . show great alteration, the iron materials being altered to limonite, and the feldspars having lost their original character, being mainly calcite and kaolin.

Bartram, however, states the alternative view, that the granitic rocks are not the basement rock, but it is his opinion that the formations

[1] E. M. Kindle, "The Fauna of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Paleontologist*, Vol. 4, No. 20 (1908).

[2] *Op. cit.*

[3] Personal communication.

[4] *Op. cit.*, p. 7.

in the lower part of the Adams well No. 1 have been metamorphosed and the granitic rock has been intruded. Thus he regards the Kevin-Sunburst anticline as possibly a large and very low laccolith. The great irregularities of structure on this anticline might thus be due to the irregularities of the intrusion.

REGIONAL STRUCTURE

By far the most prominent structural feature in the plains of southern Alberta is the northward-plunging Sweetgrass arch. Many minor irregularities exist on, and at the borders of, this great regional fold. The dip ranges from a few feet on top of the fold to as much as perhaps 200 feet per mile at its western flank.

Contrary, however, to the plunge of the Sweetgrass arch, the members of the Paleozoic formations rise northward with their bevelled edges at the pre-Jurassic unconformity.[1] This is shown on the accompanying chart. The thickness of the Madison in Adams No. 1 is about 1,100 feet, and is only 450-570 feet in the northwesternmost wells. There is also a pronounced removal from the top of the Sweetgrass arch of upper Madison beds that are present on the flanks. This indicates that the Sweetgrass arch was a prominent feature even in pre-Jurassic time. Individual lines of sections east and west, and north and south, show this aspect much better than the composite chart. Well toward the western flank of the arch, as it merges into the downwarped area of the Alberta syncline, several hundred feet of beds of upper Madison are present that have been removed from the top of the arch.

Farther north, beyond the influence of the Sweetgrass arch, but higher on the eastern flank of the Alberta syncline, because of its strike northwestward, the datum or top bed of the Devonian becomes the top of the Paleozoic, as previously mentioned in connection with the Alberta Pacific Consolidated's Duvernay well No. 1.

CONCLUSION

Within the limited area of the plains of southern Alberta, the Paleozoic formations are predominantly limestone, and would be expected to have the least change in character from place to place. However, deep drilling during the past few years has shown that many of the formations have marked differences in lithology. Exceptions to this are the strata assigned to the Jefferson dolomite of Middle Devonian age, and, to a less extent, the upper part of the Madison limestone.

[1]Theodore A. Link, "Alberta Syncline, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 491-507.

The strata assigned to the Cambrian are remarkably similar to those of the Jefferson, being limestones or dolomitic limestones. Clear water, free from clastics, characterizes this great period of limestone deposition, which is succeeded by shoaling conditions to the extent of isolation of small embayments, wherein the Three Forks sediments of Upper Devonian age were laid down as thick beds of anhydrite. The bordering lands were evidently wide, peneplaned surfaces with a mantle of soil. The Shickshockian revolution, so well understood in eastern America and the Maritime provinces of Canada, has perhaps a faint reflection in the northwestern states and the bordering provinces of Canada. The writer can not imagine the sequence of events better than that there were low lands bordering the anhydrite-depositing seas of Three Forks age. This environment ended with a relatively rapid downwarping of the sea and upwarping of the surrounding land areas, causing soils of the land to be flushed into the basin as a widespread thin sheet of black shale.

The seas were deepened by continued downwarping when pure limestone deposition prevailed. This condition was evidently accomplished earlier in central Alberta than in the south and in northern Montana. There the lower part of the Madison is shaly and sandstones also were deposited. The thick, massive, pure, white, upper Madison limestone represents one of the greatest expanses of the Mississippian epicontinental seas.

The record of the remainder of the Paleozoic is lost, for if deposits younger than the Madison were laid down in the plains of southern Alberta they were removed by pre-Jurassic erosion. The Front Range of the Rockies forms a picturesque sight from any point of the western border of that part of the plains of southern Alberta discussed in this paper. The stratigraphic sections exposed on the eastern mountain escarpments contain representatives of all succeeding periods from the Madison far up into the Cretaceous.

The great drama of events of the Mesozoic which occurred in the plains of southern Alberta and northern Montana is comparable with the sequence of events during the lower Upper Paleozoic.

AN ELLIS (UPPER JURASSIC) SECTION AT EAST BUTTE, SWEETGRASS HILLS, MONTANA[1]

JAMES O. G. SANDERSON[2]
Calgary, Alberta

ABSTRACT

The nearest exposure to the plains of southern Alberta of the marine Jurassic Ellis formation is in the Sweetgrass Hills, a few miles south of the Alberta-Montana boundary. Here it is a dark shale series containing medium-grained sandstone beds, a limestone zone, some notably fossiliferous strata, and oil showings near the base. The formation is 306 feet thick at this locality.

INTRODUCTION[3]

The Ellis (Jurassic) is one of the most important formations of the plains area in relation to the oil industry, as it is both a source and a reservoir of oil. For this reason it is desirable that as complete a description of the Ellis as possible be included in a discussion of the stratigraphy of the plains of southern Alberta. The Ellis does not crop out in this area, although Jurassic deposits are well known in the foothills and mountains bordering the plains on the west, which are generally known as the Fernie shale. The sediments in that region are approximately of the same age as the Ellis but are somewhat different lithologically, and are much thicker. On the plains of southern Alberta and northern Montana, the Ellis is known from well samples,[4] but the only outcrops of the formation within this region occur in the Sweetgrass Hills, a few miles south of the International Boundary. A

[1]Presented before the Alberta Society of Petroleum Geologists at the Calgary meeting, January 16, 1931. Manuscript received, May 18, 1931. Published by permission of O. B. Hopkins, chief geologist, Imperial Oil., Ltd., Toronto, Ontario.

[2]Geologist, Imperial Oil, Ltd.

[3]Acknowledgment is due to C. E. Erdmann of the United States Geological Survey, Denver, Colorado, who carefully criticized the manuscript of this paper.

[4]T. B. Romine, "Oil Fields and Structure of the Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), p. 789.
A. J. Collier, "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," *U. S. Geol. Survey Bull. 812-B* (1929), pp. 67-69.

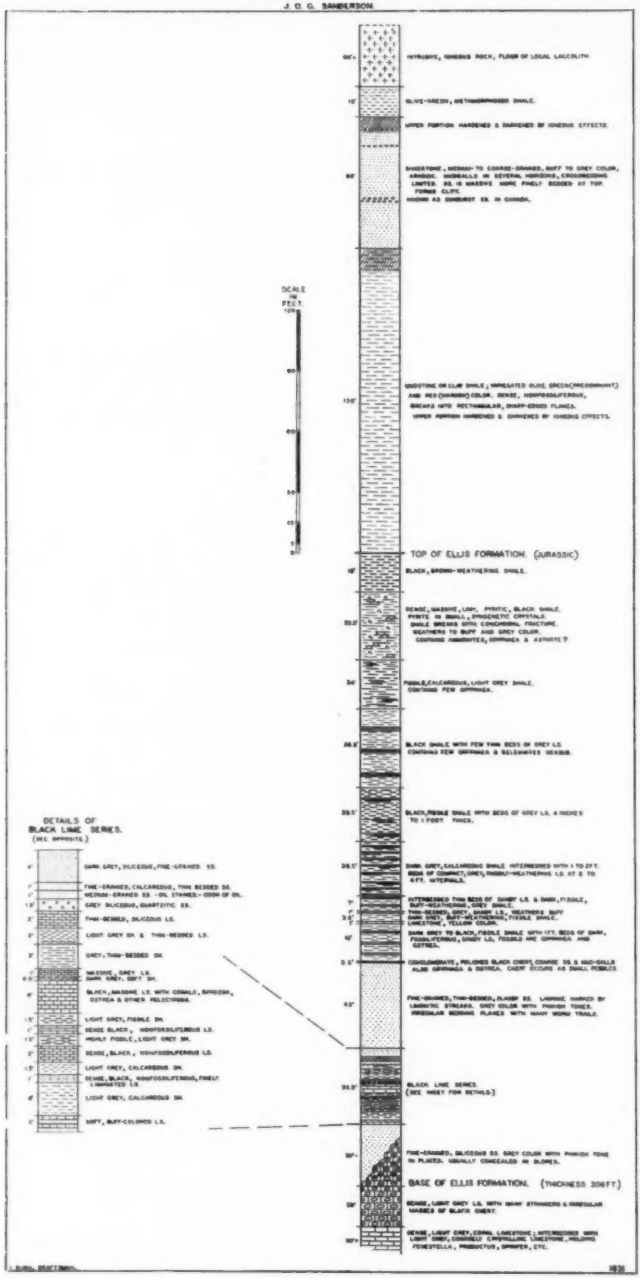

J. O. G. SANDERSON
SCALE IN FEET
TOP OF ELLIS FORMATION. (JURASSIC)
BASE OF ELLIS FORMATION. (THICKNESS 208FT)
DETAILS OF BLACK LIME SERIES.

FIG. 1.—Columnar section of Ellis formation at East Butte, Sweetgrass Hills, Montana. Sec. 8, T. 36 N., R. 5 E.

description of a complete section of the Ellis (Fig. 1), as exposed at this locality, follows.

DESCRIPTION OF STRATIGRAPHIC SECTION

The exposure described here is a result of the Sweetgrass Hills igneous uplift, and subsequent erosion. Rocks as old as the upper Paleozoic are exposed on the flanks of these intrusive masses. Because of igneous effects, there are few places where unbroken and unmetamorphosed sections of the lower formations can be found. One such locality, affording a full section of the Ellis, has long been known. It was visited and cursorily examined by S. E. Slipper[1] in 1915. This section was measured and studied by the writer during the latter part of October, 1930. It is the only complete, unmetamorphosed Ellis section thus far discovered[2] in the Sweetgrass Hills.

The section is exposed on the south side of Sage Creek in Sec. 8, T. 36 N., R. 5 E., Montana, about 7 miles south of the International Boundary (Fig. 2). The significant features are its wholly marine aspect, a preponderance of dark shale, the content of limestone and quartzose sandstone, and a profusion of organic remains which occur in the limy and sandy beds. The basal stratum of the Ellis, as shown in Figure 1, is a sandstone 30 feet thick. This sandstone differs in thickness[3] and in places is absent. The Ellis overlies Madison limestone disconformably. At the top of the section there is no clear evidence of unconformity. Dark calcareous shales, and black, brown-weathering shales pass upward into the dark greenish gray to varicolored shales of the overlying Cretaceous. However, unconformable relations would, no doubt, be disclosed in a regional study of the formation.

The possibilities of Ellis sandstone as reservoir beds are apparent at the base of the section, where two thick, relatively coarse-grained, quartzose sandstones are present. Perhaps the most interesting stratum in the section is a 1-foot layer of sandstone 63 feet above the base. This bed is dark brown to black, the coloration being caused by a residue of petroleum coating the sand grains. A strong odor of oil is noticeable when the rock is broken. The presence of black shales containing plentiful crystalline, syngenetic pyrite is a noteworthy feature. In outcrop the Ellis is quite different from the overlying Cretaceous.

[1] D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917), p. 65.

[2] C. E. Erdmann, personal communication, November, 1930.

[3] *Idem.*

A relatively complete collection of the fossils has been made, but has not been systematically studied. The identifications used to indicate the fossil zones on the graphic section (Fig. 1) were made in the field and are subject to correction. The form *Gryphaea* predominates in the

FIG. 2.—Black basal Ellis limestone overlain by sandstone, as exposed along Sage Creek, Montana. Sec. 8, T. 36 N., R. 5 E. (Photograph by Leo G. Hertlein.)

fauna of about 200 feet of the central part of the formation. The black limestone zone near the base of the section is not very fossiliferous, with the exception of one 4-foot bed which contains a rich fauna. A description of the beds is presented graphically in Figure 1.

STRATIGRAPHY OF RED COULEE OIL FIELD[1]

W. S. YARWOOD[2]
Calgary, Alberta

ABSTRACT

The Red Coulee oil field is located adjacent to the International Boundary, 5 miles west of Coutts, Alberta, and was discovered in September, 1929. The surface drift is underlain by Milk River or Virgelle sandstone. Subsurface formations are the marine Colorado shale, the Blairmore, the Ellis, and the Madison. Markers in these are described and the producing sands of the lower Blairmore are named and zoned.

INTRODUCTION

ACKNOWLEDGMENTS

The writer takes pleasure in expressing his appreciation to his former associates, T. B. Williams and H. E. Munson, for their collaboration in the field and for their numerous contributions to this paper. The accompanying north-south cross section (Fig. 4) has been prepared by Munson from well samples collected during the summer of 1930.

Theodore A. Link contributed the measured section of the Milk River sandstone.

LOCATION

The Red Coulee field is located north and south of the International Boundary in the province of Alberta and the state of Montana. In Alberta the producing area lies, at present, within sections 3 and 4, T. 1, R. 16, W. of 4th Mer., and in Montana within sections 1, 2, 11 and 12, T. 37 N., R. 4 W.

HISTORICAL SKETCH

The Red Coulee oil field was brought in during September, 1929.[3] The discovery well was Vanalta No. 1, and the productive horizon is accordingly known as the "Vanalta sand." A deeper horizon, discov-

[1]Read before the Alberta Society of Petroleum Geologists, January 16, 1931. Manuscript received, May 18, 1931. Published by permission of Alberta Pacific Consolidated Oils, Ltd., Calgary, Alberta.

[2]Geologist, Alberta Pacific Consolidated Oils, Ltd.

[3]The surface expression of Red Coulee "nose" was first recognized and mapped by Theodore A. Link in 1922.

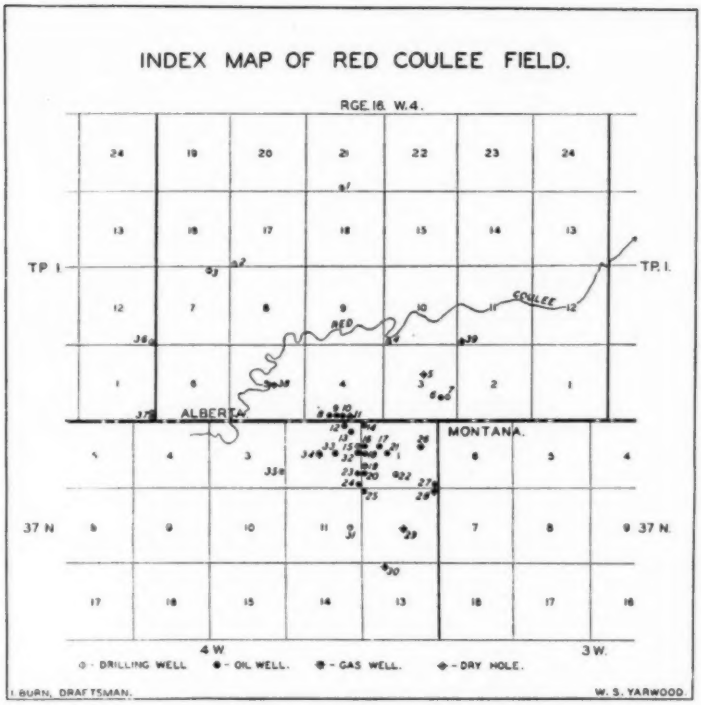


FIG. 1.—Index map of Red Coulee oil field. Wells are numbered as follows.

1. Capitol No. 1
2. Celtic No. 1
3. Dixie No. 1
4. Devonshire No. 1
5. Commonwealth No. 1
6. Southern Alberta Exploration No. 1
7. Southern Alberta Exploration No. 2
8. Taylor Syndicate No. 1
9. Vanalta No. 2
10. Vanalta No. 1
11. Alberta Pacific Consolidated No. 1
12. Midcontinent Farbo No. 1
13. Midcontinent Farbo No. 2
14. Ohio M. Farbo No. 1
15. Midcontinent Farbo No. 3
16. Inland Farbo No. 1
17. Inland Farbo No. 2
18. Rice Radigan Farbo No. 1
19. Rice Radigan Farbo No. 2
20. Monalta Buckley No. 3
21. Ohio Farbo No. 1
22. Monalta Buckley No. 2
23. Hannah Porter Iowa No. 1
24. Hannah Porter Iowa No. 2
25. Singleton Buckley No. 1
26. Huso Thomas Farbo No. 1
27. Monalta Buckley No. 1
28. Adanac Buckley No. 1
29. Amego Buckley No. 1
30. Dakota-Montana McAfee No. 1
31. Askalta Volbrecht No. 1
32. Cosmos Iowa No. 1
33. Cosmos Iowa No. 2
34. Ohio Farbo No. 2
35. Nellie J. Farbo No. 1
36. Holgar No. 1
37. Kotop No. 1 and No. 1A
38. Imperial No. 1
39. Dalco No. 1

ered in the Iowa Trust Cosmos No. 1, is known as the "Cosmos sand." The Imperial Oil Company drilled a dry hole on the same structure in 1922. This well failed to find porosity in the productive zone.

By October, 1930, there were eighteen producing wells and eight dry holes, with thirteen drilling or suspended. The average daily production of the field in January, 1931, was 550 barrels of crude oil of about 33° Bé. gravity.

STRATIGRAPHY

The rocks exposed along coulees in the vicinity of the Red Coulee district are of the upper and lower Milk River sandstone (Figs. 2 and 3). The latter is equivalent to the Virgelle.[1] Below the surface, rocks deposited during the Upper Cretaceous (Colorado), Lower Cretaceous (Kootenai), Jurassic (Ellis), and Mississippian (Madison) are known to occur.

Milk River sandstone.—Theodore A. Link[2] has kindly furnished the following brief description of the Milk River sandstone in this area.

> This sandstone is gray to buff, coarse-grained, highly cross-bedded and massive, becoming more flaggy toward the base. Ironstone concretions are fairly numerous in the upper half. In places this sandstone is composed of two distinct massive beds separated by shale seams. In Buckley's Coulee just south of the Boundary line, the following section was obtained.

Upper Milk River (*Upper Eagle*)	
Pure white, cross-bedded soft sandstone	60 feet
Lower Milk River (*Virgelle sandstone*)	
Hard, brown layer of sandstone, becoming shaly	15 feet
Dirty white, ironstained massive sandstone. Ironstone concretions becoming softer and shaly toward bottom	95 feet
White, massive, soft sandstone, ironstained bed at top, becoming more flaggy at base (base not exposed)	60 feet
Total (exposed)	230 feet

Colorado shale.—The marine shales of the Colorado group have an average thickness of 1,745 feet, but the thickness ranges from a minimum of 1,720 to a maximum of 1,800 feet. The shales are gray-black, compact, and fissile, and contain traces of aragonite, bentonite, pyrite, and ironstone. A few fossils have been noticed in certain zones, but

[1]E. Stebinger, "Possibilities of Oil and Gas in North Central Montana," *U. S. Geol. Survey Bull. 641C.*
Eugene S. Perry, "The Kevin-Sunburst and Other Oil and Gas Fields of the Sweetgrass Arch," *Montana State Bur. Mines and Geology Mem. 1* (1928).

[2]Personal communication.

very few can be identified. However, two forms, *Inoceramus* and *Baculites*, have been recognized. Such marker beds as are of importance are described later and their position is given with reference to either the top or bottom of the formation. (See Table of Stratigraphy.)

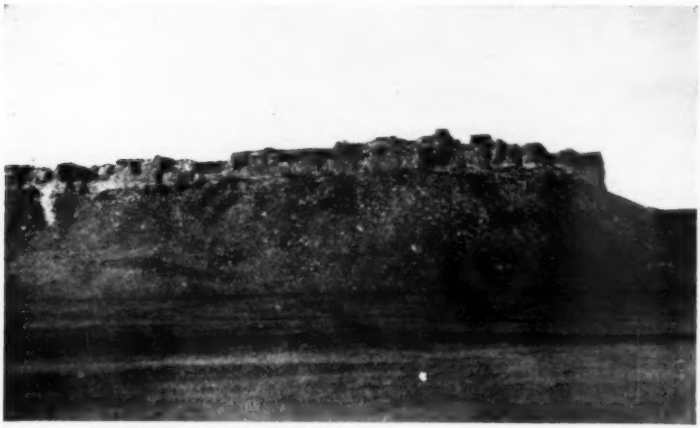


FIG. 2.—Lower Milk River (Virgelle) sandstone escarpment near Buckley Coulee, Montana. (Photograph by Theodore A. Link.)

FIG. 3.—Top of Lower Milk River sandstone as exposed along north bank of Red Coulee. T. 1, R. 16, W. of 4th Mer. (Photograph by Theodore A. Link.)

The upper 350 feet of the Colorado section consists of shale, although several non-continuous sandstone lenses are present. Bentonitic zones and ironstone bands are present, but these likewise are not persistent. The section from 350 to 400 feet has a bentonite bed which is fairly continuous and can be correlated between wells on the Canadian side of the Red Coulee field. This bed may also occur in Montana, but Colorado shale samples have not been systematically collected from

TABLE I

GENERALIZED TABLE OF STRATIGRAPHY FOR RED COULEE OIL FIELD

		Thickness in Feet	*Depth Below Surface*	*Description of Marker Beds*
GLACIAL		100	0-100	Sand and gravel of glacial origin
MILK RIVER SANDSTONE		100	100-200	Sandstone, gray, limy, mainly lower Milk River (Virgelle)
COLORADO SHALE	UPPER SHALE MEMBER	350	200-550	Shale, gray-black with minor sandstone beds and traces of bentonite and ironstone
		50	550-600	Shale as above with persistent bentonite in minor amount
		100	600-700	Shale with minor sandstone lenses, bentonite layers, and ironstone bands
		200	700-900	Shale, gray-black with traces of calcite
		280	900-1,180	Shale with minor sandstone, bentonite, and ironstone
		40	1,180-1,220	Shale, gray-black, and sandstone, gray, in about equal amount
		50	1,220-1,270	Shale with persistent bentonite in minor amount
	BLACKLEAF MEMBER	125	1,270-1,395	Shale with lesser sandstone. Top of Blackleaf member
		50	1,395-1,445	Sandstone, gray, containing fish-scales. Equivalent to Mowry
		200	1,445-1,645	Shale zone
		40	1,645-1,685	Sandstone, gray, glauconitic
		150	1,685-1,835	Shale zone
		30	1,835-1,865	Sandstone, gray, water-bearing, known as 1,800-foot water sand
		80	1,865-1,945	Shale and sandstone sections

TABLE I—*Continued*

GENERALIZED TABLE OF STRATIGRAPHY FOR RED COULEE OIL FIELD

	Thickness in Feet	*Depth Below Surface*	*Description of Marker Beds*
BLAIRMORE FORMATION	10	1,945-1,955	Red bed, but with green shale interspersed
	227	1,955-2,182	Shales, variegated, with lenses of gray sandstone
	20	2,182-2,202	Red bed
	88	2,202-2,290	Shales, variegated, and sandstone lenses
	20	2,290-2,310	Red bed
	65	2,310-2,375	Shales, variegated, and sandstone lenses
	40	2,375-2,415	Gas sand
	30	2,415-2,445	Red bed
	35	2,445-2,480	Shale, green
	70	2,480-2,550	Vanalta sand
ELLIS	60	2,550-2,610	Shales, greenish gray, calcareous
			Unconformity
MADISON	?	2,610-	Limestone, buff, crystalline

those wells. Between 400 and 500 feet from the top the section similarly consists of shale with sandstone lenses, bentonite layers, and ironstone bands. From 500 to 700 feet a massive white calcite is associated with the shales, but, as it does not seem to be confined within any part of this interval, it is not regarded as an important correlation marker. Between 700 and 980 feet the section contains gray-black shale with a few discontinuous sand lenses, bentonite beds, and ironstone bands. A sandstone occurs between 980 and 1,020 feet, which in turn overlies a 50-foot shale bed containing many thin beds of bentonite. Below this the basal 670 feet of the Colorado shale contains sandstone lenses in contrast to the section above. This thick sandy member occupies the same position in the section as the Blackleaf in the Kevin-Sunburst field of Montana. A grit bed, containing petrified fish scales and having a thickness of 50 feet, occurs abut 550 feet above the base of the Colorado. In the Southern Alberta Exploration's No. 1, Commonwealth Petroleum's No. 1, and Devonshire No. 1, water occurred in this grit, but it has not

been observed elsewhere in the field. The Capitol well No. 1 reported a showing of gas in the same zone. The position of this bed corresponds roughly with that of the Mowry shale in the Kevin-Sunburst area. A fairly persistent bed of glauconitic sandstone, having a thickness of 40 feet, is present at approximately 300 feet above the top of the Blairmore formation. This zone is not reliable as a correlative horizon because its position in the section is variable. The most persistent and reliable marker in the Colorado section is a water-bearing sandstone which has an average thickness of 30 feet. The top of this sand occurs about 110 feet above the Colorado-Blairmore contact. In many places, the sand contains chert pebbles, and, with a very few exceptions, is water-bearing. It is known in the field as the 1,800-foot water sand. The basal section of 80 feet, below the water sand, contains much sandstone in addition to the shale, but no conspicuous and persistent beds have been noted.

Blairmore formation.[1]—The Blairmore is represented by an average thickness of 595 feet of variegated shales and gray sandstones. The top occurs, on an average, at a depth of 1,945 feet below the surface. The contact between it and the overlying Colorado is generally recognized by a change from gray-black to gray-green or red shale. In some wells the top of the Blairmore is represented by a sandstone which is not essentially different from the basal member of the Colorado. In these wells the contact can be inferred by correlating the well with reference to other markers.

From the top of the Blairmore down through an average thickness of 430 feet, the sediments consist of variegated shales and sandstone lenses. As the sands range in thickness from a few feet to more than 100 feet and are not continuous, they are of no value for correlation. The lensing nature of these sands is illustrated by the accompanying section (Fig. 4) compiled by H. E. Munson. The shales within this part of the section consist mainly of gray-green and dark gray material, but there are also several noteworthy red beds which are essentially red shales, many of them bentonitic. The first of these occurs in places as high in the section as the top of the Blairmore, but is not persistent. The second red bed, in like manner, is not persistent, and where it does appear the interval between it and the top of the Blairmore is not uniform. This marker occurs at an average depth of 237 feet below the top

[1]The formational name Blairmore, as here used, refers to the part of the Cretaceous lying above the Ellis formation and below the Colorado shale. These beds are the stratigraphic equivalent of the Kootenai formation in Montana. (See T. B. Romine, "Oil Fields and Structure of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), p. 786.)

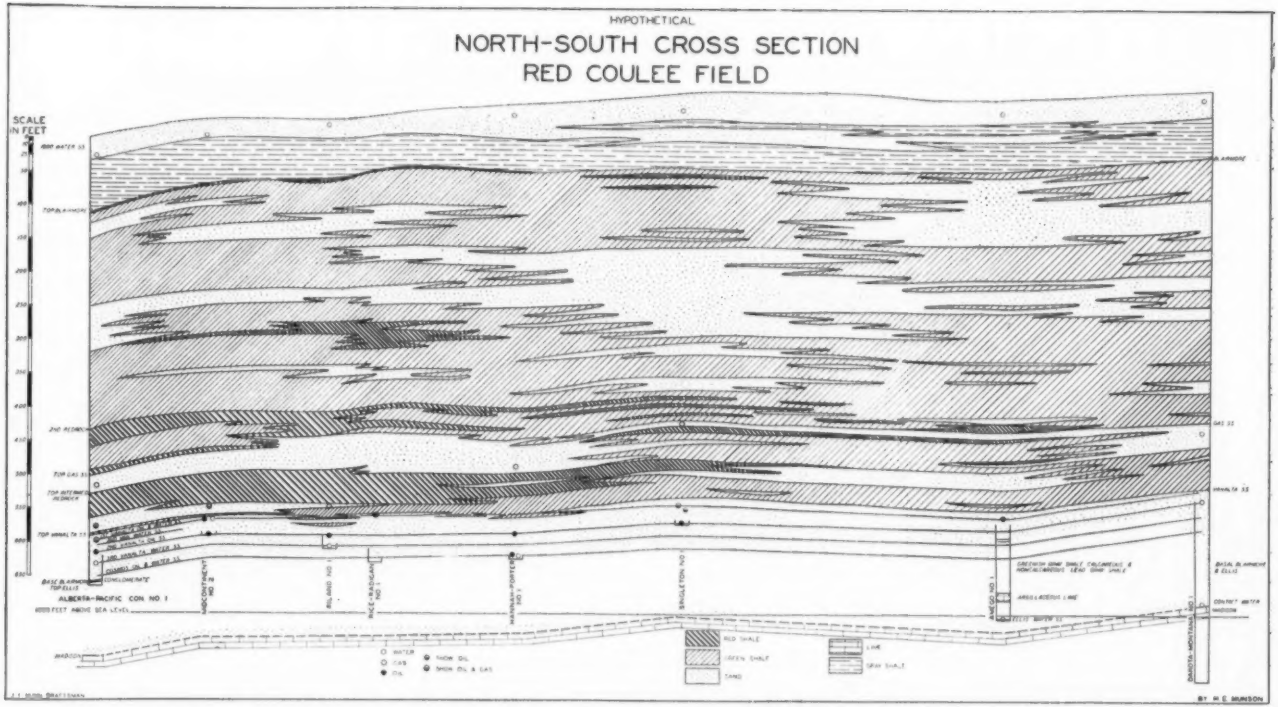


FIG. 4.—A partial cross section of Red Coulee field, showing formations from 1,800-foot water sand in basal Colorado shale down to Madison limestone. Compiled by H. E. Munson. Length of section, approximately 2 miles.

of the formation, but the interval ranges from 180 to 300 feet. The third red bed occurs at shorter intervals and has been logged in about 75 per cent of the wells. It occurs at an average depth of 345 feet below the top of the Blairmore and is considered the most important horizon in this part of the section.

About 450 feet below the contact the formation is a sandstone which contains gas within its upper part and is known in the field as the "Gas sand." This member, although having an average thickness of 40 feet, shows lateral thinning and thickening, from a minimum of 12 feet in the Amego No. 1, to a maximum of 100 feet in the Adanac No. 1. An average thickness of 65 feet separates the base of the Gas sand from the top of the Vanalta sand, although the interval ranges from a minimum of 18 feet, as in Taylor No. 1, to a maximum of 120 feet, as in Inland Pete. No. 2. This part of the section contains gray-green shale and, in some places, a fourth red bed, which occupies a position directly below the base of the Gas sand. The gas is contained in a stray sand above the basal member, or Vanalta sand. In the Adanac well No. 1 the Gas sand is continuous with the Vanalta, there being no shale interval between the two. Here the gas horizon represents the top member of the Vanalta sand.

Vanalta oil sand.—This sand has an average thickness of 70 feet and shows comparatively slight variation from this figure. Several porous zones are present in the sand and some of these, unfortunately, contain water instead of oil. The sand grains are loosely cemented and consist mainly of clear quartz and small black chert pebbles. In a core from the Alberta Pacific Consolidated's No. 1, 1 foot of chert conglomerate was obtained at the base of the Vanalta sand. This conglomerate is believed to be equivalent to that encountered in Alberta Pacific Consolidated's Spring Coulee No. 1, and also to the conglomerate which separates the Blairmore from the Kootenay in the foothills.

Table II shows the position of the porous zones within the pay sand.

Ellis formation.—The Jurassic beds have a thickness ranging from 35 to 90 feet. The average is 60 feet. They are composed mainly of greenish gray, calcareous shales, and in three wells the basal member is represented by a sandstone which is water-bearing. This horizon is possibly equivalent to the so-called Ellis sand of the Kevin-Sunburst field. In the Huso-Thomas No. 1 it was encountered at a depth of 70 feet below the base of the Cosmos sand.

Madison formation.—Several wells were drilled into the limestone, but none has encountered oil. The formation lacks porosity and con-

TABLE II

SUBDIVISIONS OF PRODUCTIVE LOWER BLAIRMORE SANDS

Thickness in Feet	*Depth Below Surface, in Feet*	*Marker Bed*
7	2,480-2,487	Gray sandstone, as a rule containing some gas. Top of Vanalta sand
7	2,487-2,494	Gray sandstone containing oil, water, or both
13	2,494-2,507	Gray sandstone. Barren zone
3	2,507-2,510	Gray sandstone, in some places containing water
5	2,510-2,515	Gray sandstone. Barren zone
5	2,515-2,520	Gray sandstone, in many places containing water
11	2,520-2,531	Gray sandstone. Barren zone
3	2,531-2,534	Gray sandstone, in some places containing water
11	2,534-2,545	Gray sandstone. Barren zone
3	2,545-2,548	Gray sandstone, may contain oil. Cosmos sand
1	2,548-2,549	Gray sandstone, may contain water. Cosmos sand
1	2,549-2,550	Chert conglomerate. Basal member of Blairmore

sists of a crystalline buff limestone. The pre-Ellis surface of the Madison seems to have had some relief and this factor, no doubt, accounts for the variable thickness of the overlying Ellis sediments.

STRATIGRAPHY OF COLORADO SHALE IN SOUTHERN PLAINS OF ALBERTA[1]

J. G. SPRATT[2]
Calgary, Alberta

ABSTRACT

A subsurface correlation of the Colorado shale extending from the Sweetgrass arch area of Montana northward to Bow River is attempted. Graphic sections are given. The Colorado shale of northern Montana continues with little change as far north as Bow Island, but farther north the top of the formation is indefinite because of the lensing-out of the overlying Milk River sandstone. The Medicine Hat gas horizon, which has previously been correlated with the Milk River sandstone, is believed to be a sand in the upper Colorado shale. The Blackleaf member of Montana can be recognized in Alberta. It contains the prominent sandstone horizon which yields gas at Bow Island and Foremost.

INTRODUCTION

Although the Colorado shale extends throughout the southern plains of Alberta, it is covered everywhere by younger sediments and all knowledge regarding its character and thickness must be obtained from well records. Scattered wells in the greater part of the area have completely penetrated the formation so that its lithology is well known.

The writer wishes to make acknowledgment to C. C. Ross, supervisory mining engineer, Department of the Interior, Calgary, for permission to publish the information contained in this paper; also to fellow members of the subsurface branch of the office for helpful criticism. The coöperation of many independent companies in submitting samples for examination to the Office of the Supervisory Mining Engineer is greatly appreciated, as well as valuable suggestions from the geological staffs of several companies.

Special acknowledgment is due to the Canadian Western Natural Gas, Light, Heat and Power Company for core-drill information from one of their test wells in the Foremost district. Photographs and descriptions of several interesting core samples were kindly furnished the author by S. E. Slipper and H. M. Hunter, geologists for the aforemen-

[1]Read before the Alberta Society of Petroleum Geologists at the Calgary meeting, February 14, 1931. Manuscript received, May 18, 1931.

[2]Assistant engineer (geologist), office of supervisory mining engineer, Department of the Interior.

tioned company. The coöperation of Theodore A. Link, geologist for the Imperial Oil Company in Alberta, in the preparation of photographic plates, is also appreciated.

STRATIGRAPHY

Sweetgrass arch section, Montana.—As the Colorado shale has been studied in considerable detail in the Sweetgrass arch area of northern Montana, a type section of that region has been used as a starting point and an attempt made to correlate it northward into Alberta. According to Perry[1] and to Collier,[2] the Colorado of the Sweetgrass arch consists of 1,750 feet of dark gray marine shales. The lower 750 feet of these are arenaceous, and to this lower part the name Blackleaf sandy member has been assigned. Bentonite occurs at different horizons throughout the Colorado, and several sandstones and conglomerates occur in the Blackleaf member.

Collier reports about forty species of invertebrate Colorado Cretaceous fauna, most of which occur in the upper 1,100 feet. He finds *Ostrea congesta*, a Niobrara species, in the upper 1,000 feet. *Inoceramus labiatus* occurs between 1,000 and 1,100 feet below the top, and fish scales, considered to be of Mowry age, are found within this zone. Species of *Scaphites*, *Baculites*, *Inoceramus*, *Ostrea*, et cetera, occur in the upper 750 feet of the formation. The lowest 400 feet of the Blackleaf is reported to be barren of marine fauna, but contains fossil wood, suggesting a Dakota age for that part of the section.

Southern Plains section, Alberta.—Most of the characteristics of the Colorado shale in the previously mentioned area continue northward into Alberta. The thickness of the formation remains approximately the same as far north as Taber and Bow Island, where its average is 1,775 feet. North of Bow Island, the upper limits of the Colorado are difficult to ascertain, because of the thinning-out of the overlying Milk River (Eagle) sandstone.

Blackleaf sandy member.—The equivalent of the Blackleaf sandy member of Montana continues northward into Alberta, where it has a maximum thickness of 700 feet on the Alberta-Montana boundary. It consists of a series of alternating dark shales and gray sandstones, several of the latter attaining considerable thickness locally. Bentonite

[1]Eugene Perry, "The Kevin-Sunburst and Other Oil and Gas Fields of the Sweetgrass Arch," *Montana State Bur. Mines Mem.* 1 (1928), Table 1, p. 5.

[2]Arthur J. Collier, "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," *U. S. Geol. Survey Bull. 812-B* (1929), p. 70.

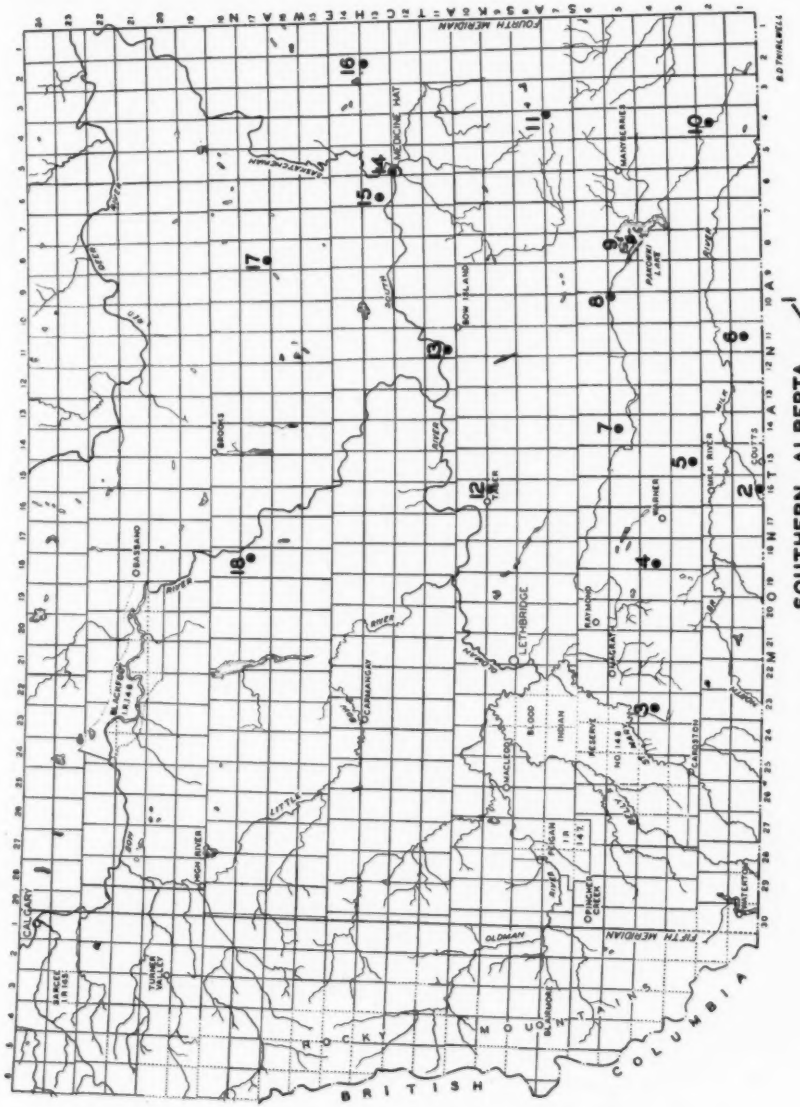


FIG. 1.—Index map of southern Alberta showing location of sections illustrated in Figure 3.

beds occur, but have not been correlated in extensive areas. The upper 300 feet of the Blackleaf equivalent in Alberta is, as a rule, less sandy than the lower 400 feet, which contains thicker and more prominent sand-

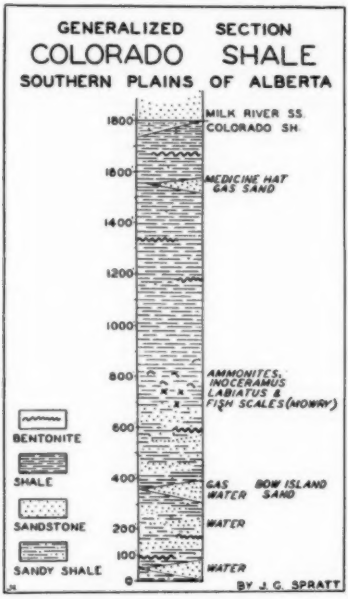


FIG. 2.—Composite section of Colorado shale. Thickness shown in feet.

stones, some of which are conglomeratic. Glauconite is commonly present in the sandstones and traces of carbonaceous laminations or thin coaly streaks are found here and there.

About 350-400 feet above the base of the Colorado a prominent sandstone, having a maximum thickness of 150 feet, occurs in the greater part of the region. This horizon is known as the "Bow Island gas sand," as it is the sand from which gas has been produced at the Bow Island field for several years. Gas is also found at this horizon at Foremost and in the Cypress Hills. As a rule, it contains water in most localities. Whether the Bow Island gas sand is one continuous horizon is not definitely known, but prominent sandstones generally occur at this point and are correlated with the gas sand of the Bow Island field.

Directly above, or in the highest part of the Blackleaf equivalent, fish scales generally occur, suggesting a correlation with the Mowry of

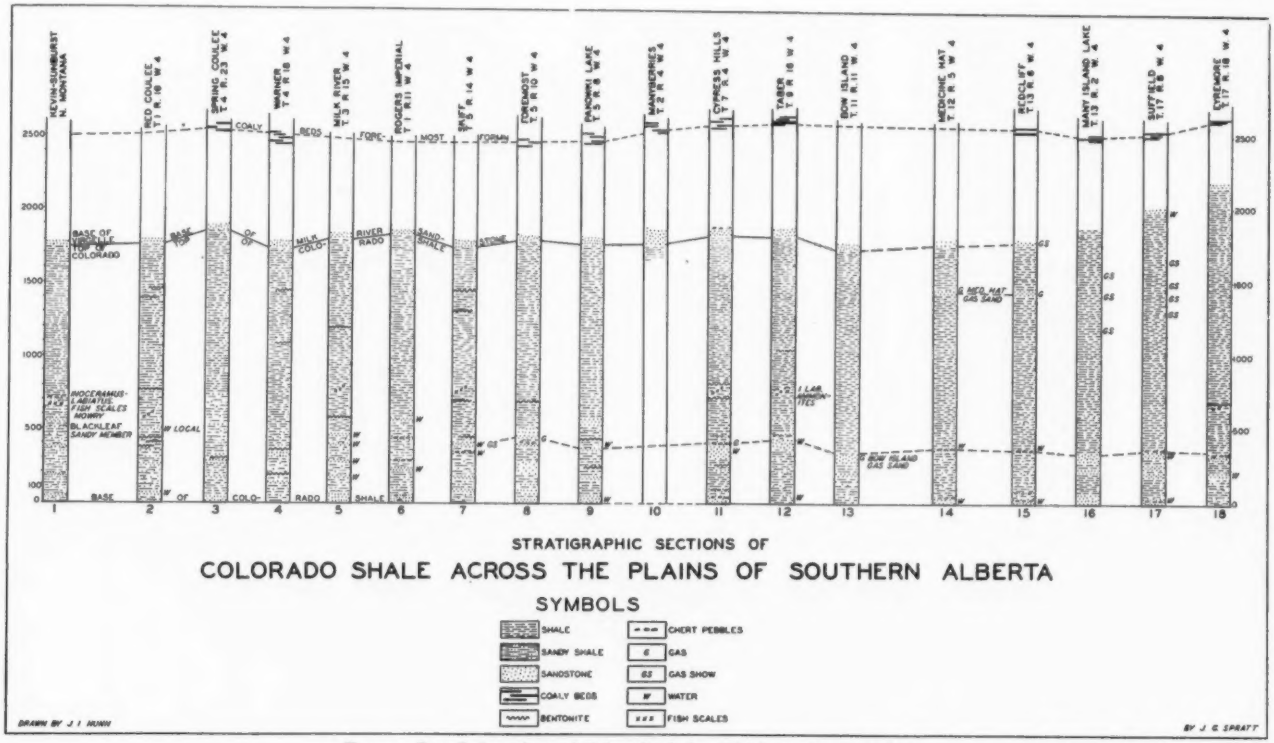

KEVIN-SUNBURST N. MONTANA
RED COULEE T 7 R. 16 W 4
SPRING COULEE T 6 R. 23 W 4
WARNER T 4 R 18 W 4
MILK RIVER T 3 R 15 W 4
ROGERS IMPERIAL T 1 R 11 W 4
SPIFF T 5 R 14 W 4
TORENDOST T 5 R 10 W 4
PANORM LAKE T 5 R 8 W 4
MANYBERRIES T 2 R 4 W 4
CYPRESS HILLS T 7 R 4 W 4
TABER T 9 R 16 W 4
BOW ISLAND T 11 R 11 W 4
MEDICINE HAT T 12 R 5 W 4
RECLIFF T 13 R 6 W 4
MANY ISLAND LAKE T 13 R 2 W 4
SUFFIELD T 17 R 8 W 4
CYPRESS T 17 R 18 W 4
2500
2000
1500
1000
500
100
0
BASE OF MEMBER NO. 1 OF COLORADO
INOCERAMUS LABIATUS FISH SCALES MOWRY
BLACKLEAF SANDY MEMBER
BASE OF COLORADO
COALY
BEDS
FORE-
MOST
FORMA-
BASE OF COLO-
RADO
MILK COLO-
RIVER RADO
SHALE
SAND-STONE
STONE
W LOCAL
E MED. HAT GAS SAND
E BOW ISLAND GAS SAND
1 LAR PHOSPHATIC NITES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
STRATIGRAPHIC SECTIONS OF
COLORADO SHALE ACROSS THE PLAINS OF SOUTHERN ALBERTA
SYMBOLS
SHALE
SANDY SHALE
SANDSTONE
COALY BEDS
BENTONITE
CHERT PEBBLES
G GAS
GS GAS SHOW
W WATER
FISH SCALES
DRAWN BY J. I. HUNN
BY J. G. SPRATT

FIG. 3.—Detailed sections of Colorado shale. Thickness shown in feet.

Montana and Wyoming. Webb[1] reports *Inoceramus* cf. *labiatus* and *Prionotropis* cf. *woolgari* in cores from a well at Taber, occurring about 1,000 feet below the top of the Colorado. This horizon is correlated with Collier's findings in the Sweetgrass arch area.

Photographs of diamond-drill core samples of some interesting horizons from the Blackleaf sandy member are shown in Figure 4. These cores are from the Canadian Western Natural Gas, Light, Heat and Power Company's test hole No. 42, in legal subdivision 1, Sec. 6, T. 7, R. 11, W. of 4th Mer., north of the town of Foremost. The following descriptions and comments on these cores were furnished by S. E. Slipper and H. M. Hunter.[2]

The top of the lower Milk River (Virgelle) was found at 613 feet in this hole, and the sandy beds were encountered at 2,067 feet, giving an interval of 1,454 feet.

Figure 4*a* is a photograph of a section of 2-inch-diameter core from 2,067 to 2,070 feet and shows sandy shale having a peculiar texture of minute interlocking lenses of light gray and dark gray material.

Figure 4*b* shows irregular lenses of dark gray shale and sandy shale, with a light gray, very fine-grained argillaceous sandstone. One chert pebble, about ¼ inch in diameter, is shown. This horizon corresponds stratigraphically with the Foremost gas sand. (See Figure 4*i*.)

Figure 4*c* is a section of core of sandy shale extending from 2,075 to 2,084 feet. This section has lenses of light gray material which in themselves are cross-bedded.

Figure 4*d* shows a section from 2,121 feet, 4 inches, to 2,124 feet, 4 inches. The groundmass in this sample is similar to those already shown, but the scattered black chert pebbles studding the rock are a noteworthy feature.

Figure 4*e* is a section of core from 2,124 feet, 4 inches, to 2,125 feet, 4 inches. This section shows finely laminated sandstone and shale with a minute lens of cross-bedded shale. Between the sand lamellae are lamellae of coal.

Figure 4*f* is a core from 2,125 to 2,129 feet. A light gray fine-grained sandstone without lamellae or other noteworthy features is shown.

Figure 4*g* is a core from 2,149 to 2,153 feet—the basal part of the sandstone shown in Figure 4*f*—showing finer grain than the section above.

Figure 4*h* is a sandstone core from 2,182 to 2,198 feet, the lower part of which is marked by distinct laminations.

Figure 4*i* shows a sample of the gas sand from the No. 7 gas well at Foremost.

Deposits having identical characteristics have been found in diamond-drill holes as far north as Burdett. However, the arrangement of beds seems to vary considerably where traced laterally. The top sandy shale shown in Figure 4*b* evidently grades into lenses of coarse sandstone as shown in Figure 4*i*.

[1]J. B. Webb, personal communication.

[2]Personal communication.

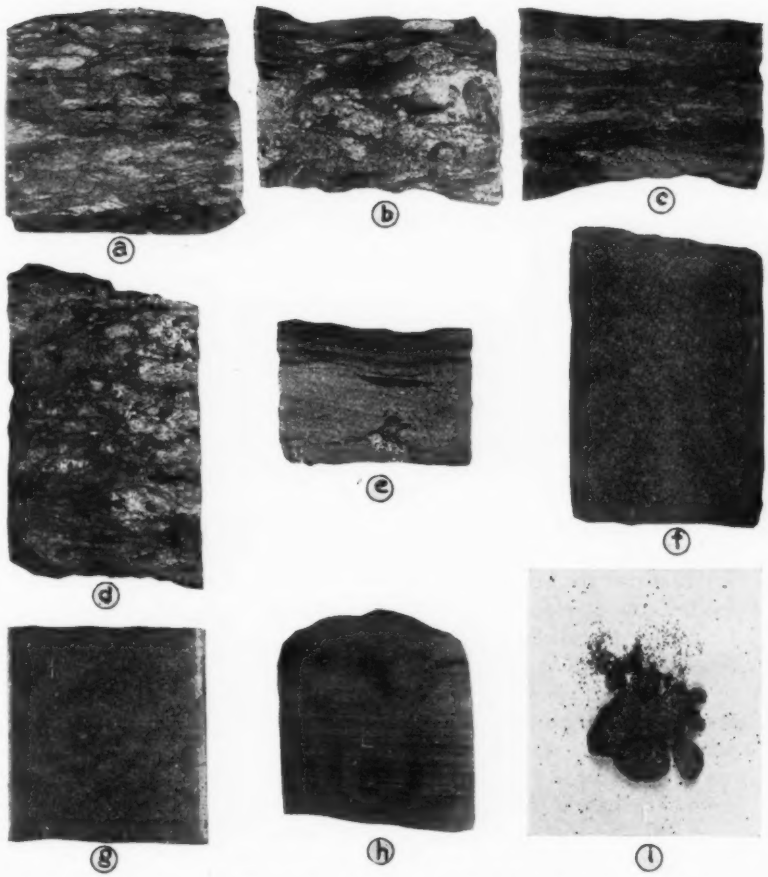


FIG. 4.—Cores and well samples showing characteristics of sandy Blackleaf member of Colorado shale. (See text for individual descriptions.)

These two samples occur at the same distance below the top of the lower Milk River sandstone. The wells are situated 7 miles apart.

Upper Colorado shale.—The upper Colorado shale consists of about 1,000 feet of dark gray marine shales with some thin, very fine-grained, sandstone beds, and bentonite horizons. Ironstone and impure limestone are present, but their irregular occurrence in samples suggests that they are concretionary rather than bedded. Any fossils which occur are generally too much broken to be recognizable. *Inoceramus* prisms are commonly found, and some fragments of *Baculites* are identified.

The highest sediments of the Colorado grade through a series of sandy shales or alternating thinly bedded sandstones and shales into the overlying massive sandstone of the Milk River formation. As this change is transitional, the Milk River-Colorado contact can rarely be determined within less than 20 feet in well samples.

CONCLUSION

The Milk River formation seems to lose its identity a short distance north of Bow Island. Because of this fact the Colorado shale merges almost imperceptibly into the Pakowki shale with essentially no record of the interfingering wedge of the Milk River sandstone.

The productive gas horizon at Medicine Hat and Redcliff has heretofore been correlated with the Milk River sandstone,[1] which overlies the Colorado shale farther south (Fig. 3). More recent drilling, however, indicates that the Medicine Hat gas sand occurs in the Colorado, about 300 feet stratigraphically below the true Milk River horizon. The reason for placing the Medicine Hat gas sand within the Colorado shale can best be explained by reference to Figure 2. In this diagram a series of sections of the Colorado in the southern plains is shown. Some sections also show the relative position of the coaly series of the Foremost formation with respect to the upper and lower limits of the Colorado. It can be seen that in every locality where a section from this coaly series down to the base of the Colorado is known the thickness is approximately 2,500 feet, and that the interval from the coaly series down to the top of the Colorado is about 700 feet.

At Medicine Hat and Redcliff, however, it is seen that the interval from the coaly beds to the Medicine Hat gas sand is about 1,000 feet,

[1] D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917), p. 48.
G. S. Hume, "Oil and Gas in Western Canada," *Geol. Survey of Canada Econ. Geol. Series 5* (1928), p. 50.
M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem.* 163 (1930), pp. 116-20.

whereas the interval from the latter horizon to the base of the Colorado is about 1,500 feet. In other words, the interval from the coaly series to the base of the Colorado is uniform, namely, about 2,500 feet, but the Medicine Hat gas horizon occurs too close to the base of the Colorado and too far below the coaly series of the Foremost formation to be correlated with the Milk River formation. It is, therefore, concluded that the position of the Medicine Hat gas sand is within the upper part of the Colorado formation at a distance of about 300 feet below the Milk River sandstone, with which it has been previously correlated.

STRATIGRAPHY OF FOREMOST, PAKOWKI, AND MILK RIVER FORMATIONS OF SOUTHERN PLAINS OF ALBERTA[1]

S. E. SLIPPER[2] and H. M. HUNTER[3]
Calgary, Alberta

ABSTRACT

The Foremost formation consists of continental material deposited during a regression of the Montana sea. Three important members are identified. The Pakowki formation is described as the marine sediments of a transgressing Montana sea. Details of local sections are given and it is shown that the sea transgressed from the southeast. The two divisions of the Milk River formation are described as the regressional deposits of the retreating Colorado sea. The upper part was derived from a land mass southwest of the area.

ACKNOWLEDGMENTS

The information on which this paper is based was obtained chiefly from the explorations of the Canadian Western Natural Gas, Light, Heat and Power Company, Ltd. The core records of diamond-drill structure test holes supply a large part of the data. In addition, acknowledgment is due to the Lethbridge Brewing Company for the log of a well drilled on their property; to the supervisory engineer of the Department of the Interior for a log of a Medicine Hat well; and to Theodore A. Link for measured sections of the Milk River formation. Sections obtained from the contour map of Bears' Den, Flat Coulee, and Whitlash districts, Montana, by C. E. Erdmann,[4] were also used.

INTRODUCTION

It is not the intention of the writers to enter into a critical discussion of work done by others in describing these strata. The pioneer work

[1]Read before the Alberta Society of Petroleum Geologists, February 14, 1931. Manuscript received, May 18, 1931. Published by permission of Canadian Western Natural Gas, Light, Heat and Power Company, Ltd., Calgary, Alberta.

[2]Chief geologist, Canadian Western Natural Gas, Light, Heat and Power Company, Ltd.

[3]Geologist, Canadian Western Natural Gas, Light, Heat and Power Company, Ltd.

[4]C. E. Erdmann, *Preliminary Structure Contour Map of Bears' Den, Flat Coulee, and Whitlash Districts, Montana* (U. S. Geol. Survey, 1930).

of G. M. Dawson[1] was surveyed in a thorough manner by Dowling.[2] In Dowling's memoir on the "Southern Plains of Alberta" the reader may find the authority for the divisions and formational names used in this paper. In a report by Williams and Dyer,[3] received while this manuscript was in preparation, a radical change in the meaning of the group and formation names from that of Dawson and Dowling is introduced. Although there may be well founded reasons for making the Belly River of less extension, it is believed that most geologists will prefer to retain it as a group name; hence, Dowling's arrangement is retained by the writers.

TABLE OF FORMATIONS

Formation (Alberta)	*Member (Alberta)*	*Formation (Montana)*	*Member (Montana)*
Foremost	Taber coal horizon McKay coal horizon	Judith River (in part)	
Pakowki	Verdigris sandstone	Claggett	
Milk River	Upper Milk River	Eagle	Upper Eagle
	Lower Milk River (Virgelle sandstone)		Virgelle

FOREMOST FORMATION

Dowling[4] named the brackish-water, yellow beds of Dawson the Foremost formation, his type locality being the exposures in Chin Coulee near the town of Foremost. Not all the related beds are exposed at the type locality and he described his basal section from the exposures near Medicine Hat. However, the sediments near Medicine Hat are different from those characterizing the lowest Foremost in most places and, because of this variation, his generalized section is not typical.

The Foremost formation is not easy to describe because its chief characteristic is the variable stratification. Measured sections are gen-

[1]G. M. Dawson, "Report on Region in Vicinity of Bow and Belly Rivers, Northwest Territories," *Geol. and Nat. Hist. Survey of Canada Rept. of Progress 1882-83-84.*

[2]D. B. Dowling, "Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917).

[3]M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930), p. 15.

[4]D. B. Dowling, "Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917), p. 37.

erally quite unlike each other even when short distances intervene. All geologists have difficulty in placing the dividing line between the Foremost and the overlying Pale beds. In some places it is quite impossible to make the division. Dowling defined the top of the Foremost as a "certain coal seam." This is the seam mined at Taber, the position of which is not definite except locally.

The generalized section compiled chiefly from the diamond-drill cores of structure test holes is here given. This section should be compared with the drill-hole sections shown in Figure 2.

Yellow Massive Sandstone (Pale Beds)		*Thickness in Feet*
Top, 1.	Carbonaceous shale Coal seams Ferruginous limestones (Taber coal horizon)	100
2.	Sandstones and shales in thicker units than below	120
3.	Thinly interbedded carbonaceous shales, sandstones, sandy shales Ferruginous limestones *Ostrea* beds	100
4.	Colloidal clays and coal seams (McKay coal horizon and sandstone)	60
5.	Basal sandstone (Verdigris sandstone)	60
	Total (Foremost)	440
	Marine transition beds (Pakowki shale)	

At the base of the overlying Pale beds there is, in the southwestern part of the region, a massive buff-weathering sandstone. It is easily recognized in outcrops and wherever it occurs serves definitely to locate the upper limit of the Foremost formation. Typical exposures may be observed on Oldman River west of the town of Taber, on the prominent topographic "high" known as the Chin, about 5 miles south of Barnwell, in Verdigris Coulee at the head of Tyrrel Lake, in the small coulees between Sterling and Warner, and also on Milk River at the mouth of Mackie Creek. In districts where this sandstone does not occur and where the top of the Taber coal horizon is indefinite the division between the Foremost formation and the Pale beds must be made arbitrarily.

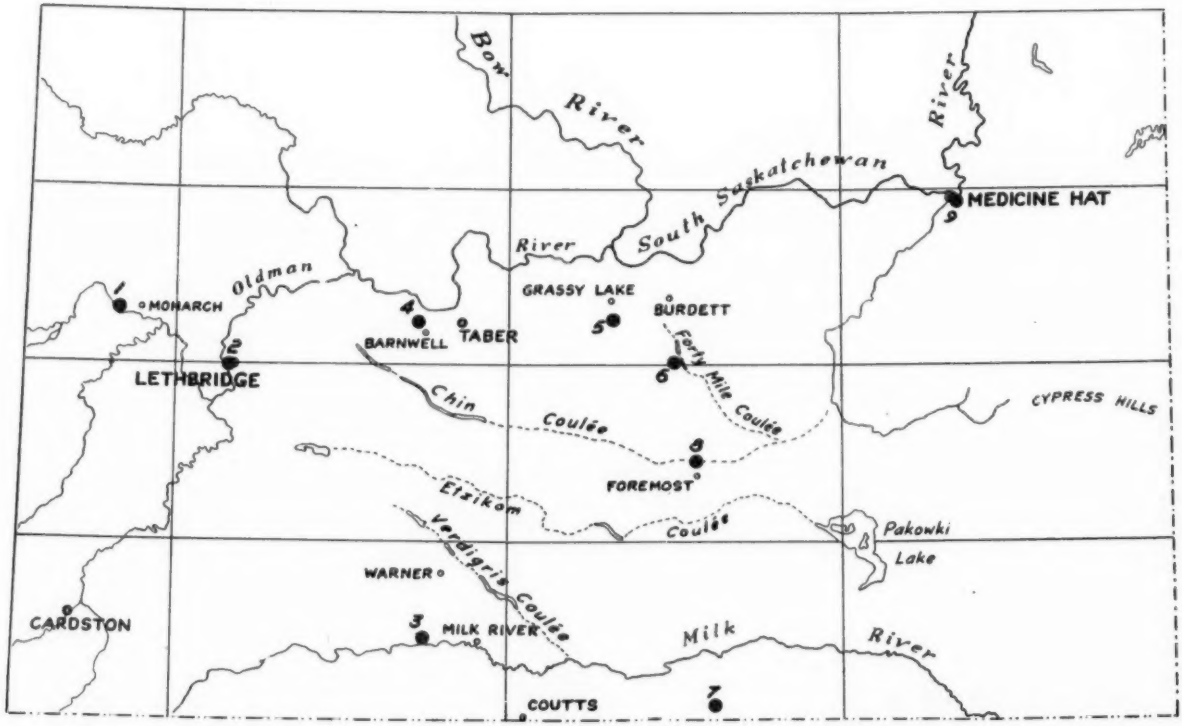


FIG. 1.—Index map showing localities of sections. Numbers refer to sections in Figure 2. East-west length of area mapped, approximately 156 miles.

The following comparative criteria may help in making an approximate division of the Foremost or Pale beds.

Pale Beds	*Foremost Beds*
Long cross-bedding, typical	Not typical
Not typical	Ferruginous limestone bands typical
Not typical (except in coal at top)	Coal and carbonaceous shales typical
Thick beds of sandstone common	Mostly thin-bedded
Light grays, light greens, yellows	Dark colors predominate

Taber coal horizon.—Along Oldman River north of Taber, coal has been mined for years from seams at the top of the Foremost formation. The coal seams are decidedly lenticular and it is impossible to use them as horizon markers. This coal series in most of the region is about 100 feet thick, but toward the west and southwest it loses its identity and becomes a thin zone of coaly shale.

Beneath the coal horizon occurs a group of thick cross-bedded and lenticular sandstones, which could be mistaken for members of the Pale beds. *Unio* is a common fossil in this part of the Foremost.

Middle Foremost.—Most of the exposures in the region are of the middle Foremost. These beds show a heterogeneous stratification that is indescribable. As an example of the extreme alternation of rock types the following section is a description of 6 feet of diamond-drill core from a structure test near the town of Barnwell.

Feet	*Inches*		*Feet*	*Inches*	
314		to	315	11	Dark brown carbonaceous shale
315	11	to	316		Ironstone
316		to	316	1	Argillaceous sandstone
316	1	to	317	6	Dark gray carbonaceous shale
317	6	to	319	10	Light gray argillaceous sandstone
319	10	to	320		Light brown ferruginous limestone

Such variations are typical of the middle part of the Foremost. There are about 100 feet of middle Foremost beds. Near the town of Foremost there are two prominent beds, almost entirely composed of *Ostrea* shells, which merge into one bed if traced out. In other districts such prominent *Ostrea* beds have been observed in exposures and in the cores of structure test holes, but there is evidence that most of these are lenticular zones which occur in places in the middle Foremost. The writers are convinced that there is neither a bed nor an interval in all this part of the Foremost that can be used for mapping structure. The exposures with their thin-bedded aspect suggest a profusion of definite horizons, but careful core work has proved the extreme discontinuity of all these beds.

McKay coal horizon.—The middle beds grade downward into a coal horizon approximately 60 feet thick. The McKay coal seam in the lower part of the horizon is workable at some localities. There are good exposures of this horizon on Milk River about 9 miles west of the town of Milk River and in Verdigris Coulee. Drill holes encounter the horizon throughout the whole region, and the coaly beds at river level near Medicine Hat probably belong here. At the base some greenish white colloidal clay (bentonite ?) beds have been used by A. J. Childerhose[1] as a horizon marker. The lowest coal seam is also a good marker.

Verdigris sandstone.—The basal sandstone of the Foremost is the most persistent member of the formation. It is proposed to call it the "Verdigris sandstone" because it is best exposed at three localities in the coulee of that name. It is also fully exposed along Milk River at intervals for 7 miles west of the town of Milk River. The Verdigris sandstone does not occur in the basal sections of the Foremost exposed along South Saskatchewan River west of Medicine Hat. Nor is it recognized in the samples from the well at Lethbridge (*2* of Figure *2*). The base of the sandstone is transitional into the underlying Pakowki shale to such an extent that it is difficult to place the division line between the two. The upper limit of the sandstone is definite at most localities. On exposures the sandstone is buff, and in core samples it is light gray and medium-grained. The thickness of the member has a considerable range, but in general it increases southward and southwestward where it is about 60 feet thick.

Origin.—The Foremost formation consists of sediments probably derived from the southwest and deposited during a regression of the lower Montana sea. The Verdigris sandstone represents the beach sands of the retreat; the remainder, consisting in large measure of vegetable débris and chemical precipitates, represents lagoonal deposits of a low land with sluggish sedimentation. The succeeding Pale beds, of clean sands, containing a minimum of vegetable material and with long cross-bedding, indicate rapid sedimentation on a steeper gradient. This history of sedimentation suggests a three-part division of the regressive overlap contained in the Foremost formation and Pale beds: (1) beach sands, represented by the Verdigris sandstone; (2) lagoon deposits, represented by the middle and upper Foremost; and (3) delta-type deposits, represented by the Pale beds.

[1]Personal communication.

It is suggested that theoretically these three divisions should appear in all the regressive overlaps of the Plains region. The beach-sand deposits and the lagoon deposits are clearly present in the Kootenai, in the Milk River, and in the Fox Hills-St. Mary River overlaps, but the overlying delta-type beds are not everywhere present.

Paleontology.—The Foremost formation contains both fresh-water and brackish-water types. Fossils are plentiful throughout the formation, and in places there are beds consisting entirely of *Ostrea subtrigonalis*. Thin seams consisting almost wholly of *Corbula perundata* shells are also common. Probably the best discussion of the paleontology of the Foremost beds that has been written is in the recent work of M. Y. Williams and W. S. Dyer.[1]

PAKOWKI FORMATION

A series of marine shales and sandstones found between the continental deposits of the Milk River and the Foremost formation was named "Pakowki" by D. B. Dowling[2] in 1915. The name originated from the locality of an exposure of these beds in Pakowki Coulee. This exposure was noticed by G. M. Dawson[3] in 1882, but he considered that it was a part of the Colorado formation. In 1905, Stanton and Hatcher,[4] of the United States Geological Survey, showed that these beds were of lower Montana age and correlated them with the Claggett of northern Montana.

Exposures of the Pakowki are scarce and incomplete. However, along Milk River, about 7 miles west of the town of Milk River, an excellent exposure of the top of the formation may be seen. This exposure, together with the records of several core holes in the vicinity, supply the best available information concerning the Pakowki in the entire area of the Southern Plains.

In the Milk River district the formation has a thickness of 183 feet. The base is distinctly marked, in many places, by a thin chert conglomerate, and otherwise by typically continental deposits of green shale or light gray sandstone of the Milk River formation. There is a phase in the middle consisting of marine sandstone, sandy shale, and a little

[1] "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930).

[2] D. B. Dowling, "Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917).

[3] G. M. Dawson, *Geol. Survey of Canada Rept. of Progress 1882-84.*

[4] T. W. Stanton and J. B. Hatcher, "Geology and Paleontology of the Judith River Beds," *U. S. Geol. Survey Bull. 257* (1905).

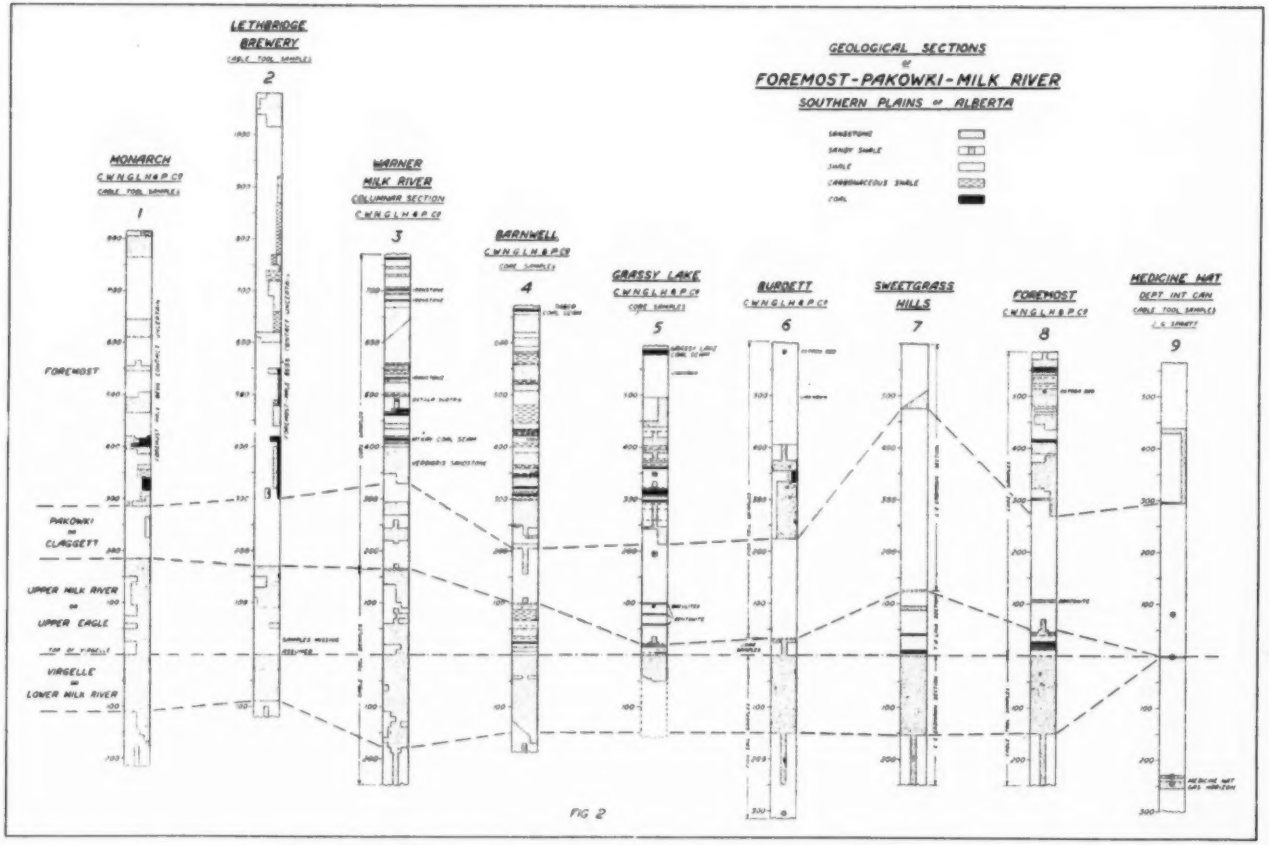


FIG. 2.—Geological sections of Foremost-Pakowki-Milk River. Vertical scale in feet.

shale, having a thickness of 75 feet. The top of the formation is shown by a fairly sharp change from dark interbedded marine shales and sandstones to the light yellow basal sandstone of the Foremost. The remainder of the formation consists of a dark blue-gray shale with some sandy shale. It is important to notice that this is the only locality where the top of the formation may be located with any accuracy. The section is as follows.

Thickness in Feet	*Description*
23	Interbedded dark blue-gray shales with fine-grained sandstones
25	Dark blue-gray shale (some cone-in-cone calcite near the top)
25	Greenish to gray fine-grained sandstone
25	Dark blue-gray shales, sandy shales, and fine-grained sandstones. This horizon varies laterally, the shales and sandstones replacing one another
25	Greenish to gray fine-grained sandstone
10	Dark blue-gray sandy shale
40	Dark blue-gray shale
10	Dark blue-gray shale and sandy shale
183	Total Pakowki

From the record of a cable-tool hole, the Pakowki has a thickness of about 100 feet near Monarch (*1* of Figure 2). It consists of dark gray shale with a sandy phase in the upper part. The base of the formation is marked by the contact with a light gray sandstone of the Milk River formation. The top is fairly well shown by a change from sandstone and carbonaceous shale of the Foremost to dark gray shale. The section is as follows.

Thickness in Feet	*Description*
20	Dark gray shale
40	Dark gray shale with sand
40	Dark gray shale

At Lethbridge (*2* of Figure 2) the formation has a thickness of about 130 feet, as shown in the cable-tool samples from the Lethbridge Brewery well, and consists entirely of dark gray shale. The contact with the underlying Milk River formation is between the shale and a light gray sandstone. The top of the formation is marked by sandy shale and some coal.

At Barnwell (*4* of Figure 2) four complete cores of the Pakowki have been obtained. Here, the thickness is about 110 feet. The base is distinctly marked, in some places by a thin chert conglomerate, in others by a green shale, and in others by a light gray sandstone of the upper

Milk River. The basal 20 feet consists of sandy shale; above it there are 40 feet of dark blue-gray shales, which are covered by 50 feet of dark blue-gray sandy shales. There is great difficulty in determining the top of the formation. From 50 to 100 feet of transitional sandstones, sandy shales, and shales are found, grading into the Verdigris sandstone. The lack of definitely marine fossils and the occurrence of plant remains here and there in these transitional beds have led to their inclusion in the Foremost. The section is as follows.

Thickness in Feet	*Description*
50-100	Transitional beds of sandstones, shales, and sandy shales (Foremost)
50	Dark blue-gray sandy shales
40	Dark blue-gray shales
20	Dark blue-gray sandy shales

A complete core of the Pakowki has been taken about 5 miles south of the town of Grassy Lake. The thickness at this point is 190 feet. The base of the formation is marked by a chert pebble bed. About 30 feet of dark blue-gray sandy shales lie on top of the pebble bed. The remainder of the formation is made up of typically marine dark blue-gray shale, except for a small sandy phase near the top. Some bentonite beds occur in the lower part. These have a peculiar greenish brown color when first recovered (provided they had not been water-soaked), but change to a very light gray on exposure to the air. About 30 feet of transitional beds at the top were included within the Foremost.

In the Burdett district only a few feet of the lower part of the Pakowki has been cored. From fish-tail-sample evidence the formation seems to be about 195 feet thick. It consists of dark blue-gray shale with a little sandy shale near the top and bottom. Some bentonite occurs. The base is marked here and there by a chert conglomerate; otherwise the formation grades into the sandy shales of the upper Milk River formation. There is a transitional zone at the top, but its actual extent is not known.

C. E. Erdmann[1] gives a thickness of 350-420 feet to the Pakowki formation in the Sweetgrass Hills. He describes the beds as "greenish gray and drab fissile marine shales with thin sandstone lentils." Both Theodore A. Link[2] and C. E. Erdmann show a pebble bed marking the base of the formation.

[1]C. E. Erdmann, *Preliminary Structure Contour Map of the Bears' Den-Flat Coulee-Whitlash Districts of North Central Montana* (U. S. Geol. Survey, July, 1930).

[2]Personal communication.

At Foremost the Pakowki formation has been completely cored except for 20-30 feet of the upper part. It has a thickness of 220 feet. The base is fairly well marked by a rapid change from dark blue-gray sandy shales to continental deposits. About 20 feet at the base consists of sandy shale; the remaining 200 feet is a dark blue-gray shale which has one prominent bentonite bed about 60 feet above the base. Approximately 20 feet of transitional beds occur at the top and have been included in the Foremost.

The log of a Medicine Hat well is shown in Figure 2. It shows a thickness of 290 feet to the Pakowki, where it evidently consists of soft dark shale.

Paleontology.—In the upper 25 feet of the formation the form *Liopistha undata* is characteristic and fairly common in the district around the town of Milk River. The sandstones of the middle part of the formation where exposed are generally fossiliferous, the most common form being *Pteria nebrascana*. In southeastern exposures and in cores *Baculites compressus* is a prominent form.

Origin.—The sediments of the Pakowki were deposited during a rapid transgression of the lower Montana sea over the continental sediments of the upper Milk River formation. The isopach map (Fig. 3) shows the deposition of the formation which thickens rapidly toward the southeast.

In the eastern part of the plains area the Pakowki is composed almost entirely of shale; in the southwest a sandstone phase occurs near the middle. In localities west of the town of Milk River it is possible that the formation consists entirely of sandstone, this being a further development of the middle sandstone phase.

MILK RIVER FORMATION

In 1905 Stanton traced the Eagle sandstone from Montana into Alberta and proved that the beds which Dowling several years later named the Milk River formation, were identical and continuous with the Eagle formation. Under the circumstances a new name was not justified and the formation should have been named "Eagle." Usage in Canada, however, has forced the name "Milk River" to stand. In later years some geologists have accepted the name "Virgelle" for the prominent basal member of the formation, which is the name applied to it in Montana. The Geological Survey of Canada, however, still refers to the two divisions as the upper Milk River and the lower Milk River.

The formation as a whole consists largely of light-colored beds. The greatest thickness in the west, the Warner section (3 of Figure 2), is

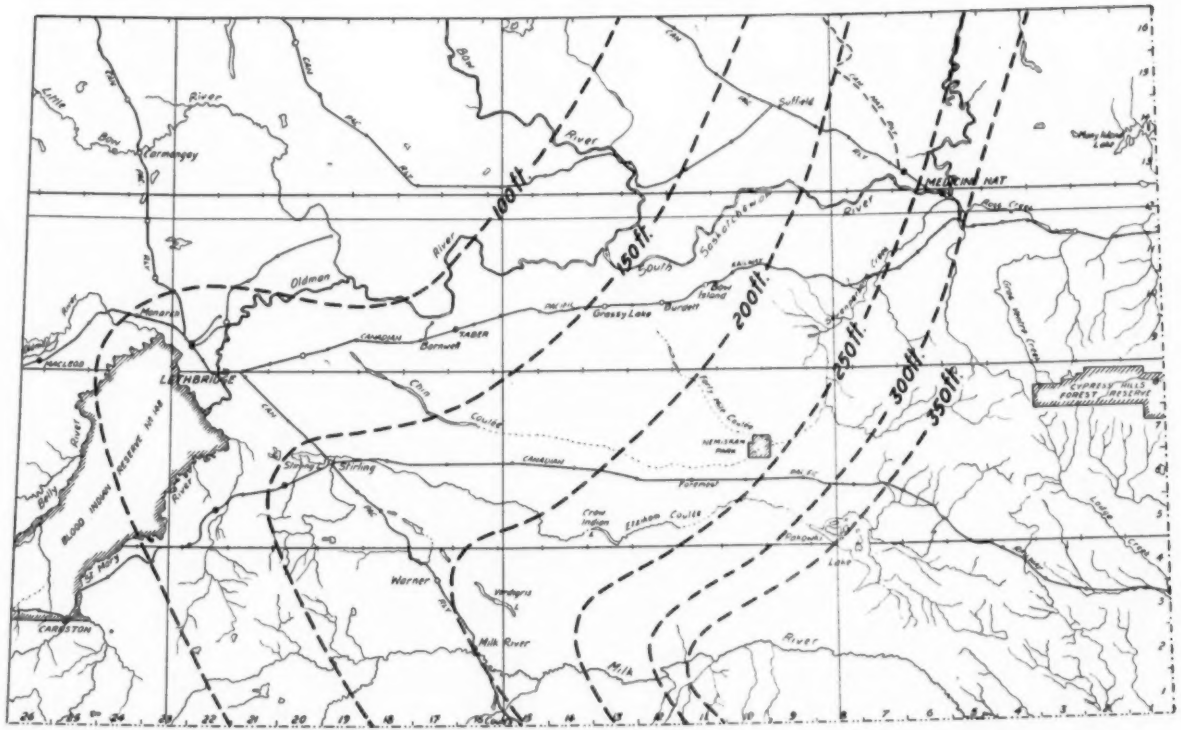


FIG. 3.—Isopach map of Pakowki formation. Townships numbered at right; ranges at bottom; each approximately 6 miles wide.

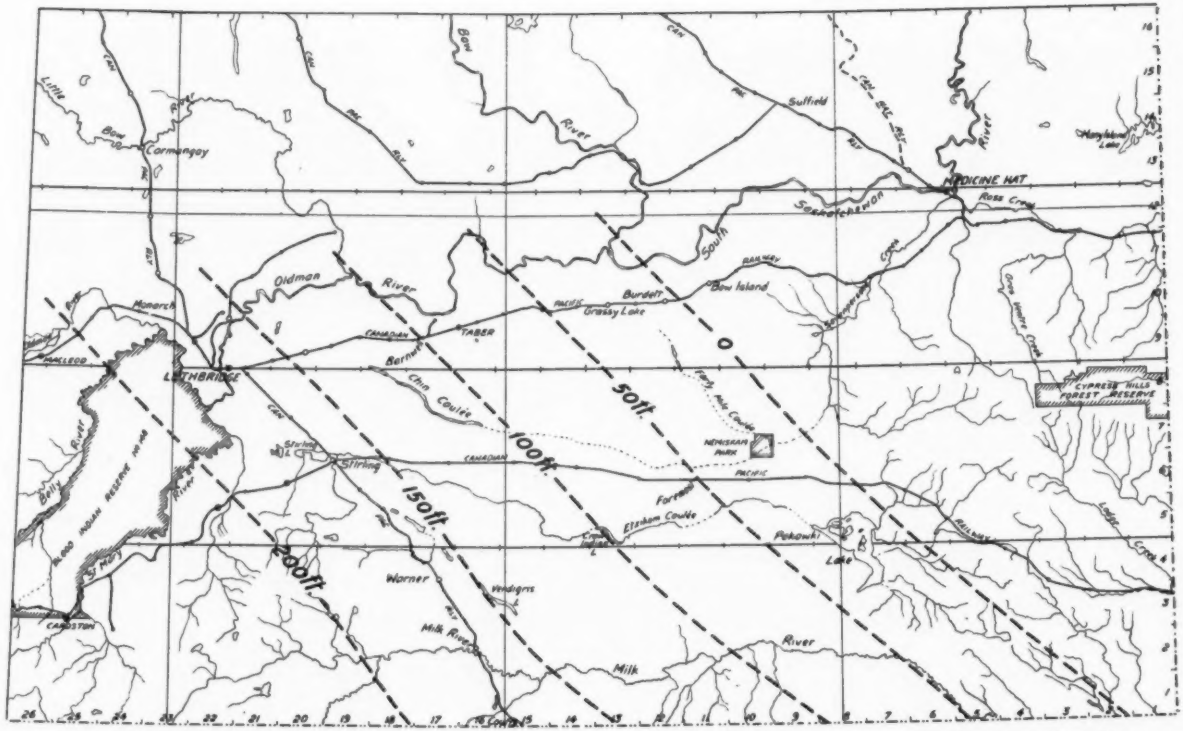


FIG. 4.—Isopach map of upper Milk River beds. Townships numbered at right; ranges at bottom; each approximately 6 miles wide.

FIG. 5.—Lower Milk River formation on Milk River. Viewed southwest from NE. cor., Sec. 36, T. 1, R. 13, W. of 4th Mer. The "Bad-lands" weathering is typical. (Photograph by Delmer L. Powers.)

FIG. 6.—Exposure of top massive part of Lower Milk River sandstone at mouth of Verdigris Coulee, Sec. 12, T. 2, R. 14, W. of 4th Mer. (Photograph by P. D. Moore.)

FIG. 7.—Typical exposure of Upper Milk River sandstone on west slope of Verdigris Coulee in Sec. 30, T. 2, R. 14, W. of 4th Mer. (Photograph by P. D. Moore.)

FIG. 8.—Foremost-Pakowki contact exposed on bank of Milk River in Sec. 30, T. 2, R. 17, W. of 4th Mer. (Photograph by J. O. G. Sanderson.)

345 feet, though at Medicine Hat it is about 10 feet. The formation is exposed in a large area along the Montana border, where the average thickness is 280 feet. In Alberta the formation is surprisingly barren of fossils, the few forms found being plant remains.

Upper Milk River.—The upper Milk River thins out within a few miles toward the northeast as shown by the isopach map (Fig. 4). At the top an extraordinarily persistent black chert pebble bed is found capping the exposures and in many of the core sections. However, this bed is not found in the wells at Foremost, Lethbridge, or Monarch. The pebble bed ranges from a fraction of an inch to 6 inches in thickness. In some places a thick cross-bedded sandstone occurs beneath the pebble bed, but generally it is succeeded by a series of green shales, carbonaceous shales, thin coal seams, and thin sandstones.

Lower Milk River.—The lower Milk River or Virgelle is a massive sandstone which has a clean-cut contact with the overlying member, whereas the base grades into the underlying Colorado shale through a series of transition beds. The member has a fairly constant thickness throughout a large part of the region, but from the vicinity of Foremost it decreases in thickness within a few miles toward the northeast.

The lower Milk River is very light-colored on exposure, almost white. The upper part is irregularly indurated and weathers into castellated forms. In core samples the lower Milk River is a medium-grained, light gray sandstone. Porous zones yield artesian flows of fresh water.

Origin.—The Milk River formation comprises the regressive deposits formed during the retreat of the Colorado sea. This deposition was probably the result of an upwarp southwest of the region.

The beach sands of the retreating sea are represented by the lower Milk River, lagoon deposits by the carbonaceous shales and coal seams of the upper Milk River, and the deltaic deposits by the pebble bed and its associated sands at the top of the formation. Thus there is the three-part division of this regressive overlap which was also observed in the Foremost-Pale beds overlap.

SUBSURFACE STUDY OF PALE BEDS AND FOREMOST FORMATION IN LETHBRIDGE-BROOKS AREA OF SOUTHERN ALBERTA[1]

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ABSTRACT

In this paper is presented the subsurface information concerning the Pale beds and the Foremost formation as disclosed by seven deep wells drilled in the Lethbridge-Brooks area of Alberta. The nomenclature of the formations and some regional aspects of lithology, sedimentation, and thickness are considered briefly. These formations are Cretaceous in age, and are the equivalent of the Judith River beds of Montana.

The Foremost formation consists largely of brackish-water, lagoonal deposits of dark gray shales with subordinate sandstone, carbonaceous matter, and oyster beds. A prominent coal series (McKay) is recognized near the base, and another coal horizon (Taber) is present at the top of the formation in some parts of the area. The average thickness of the formation is 400 feet, but it is somewhat less farther northeast.

The Pale beds consist chiefly of fresh-water deltaic deposits of light gray sandstones and shales. A widespread coal series (Lethbridge coal measures) is present at the top. The formation is about 740 feet thick in the southwestern part of this area, but becomes thinner northeastward.

Stratigraphic evidence indicates that some western land mass was the source of the sediments. Persistent coal measures at the base of the Foremost and the top of the Pale beds are useful for correlation.

INTRODUCTION

The purpose of the writer is to discuss briefly the nomenclature of the Pale beds and the Foremost formation, and mainly to present the results of a subsurface study of those sediments as found in well sections from Lethbridge to Brooks, Alberta, together with a few remarks concerning some regional characteristics.

ACKNOWLEDGMENTS

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[2]In charge of geology, Hudson's Bay Oil and Gas Company, Ltd.

Company, Limited, the management of the Lethbridge Breweries, Limited, and the Hudson's Bay Oil and Gas Company, Limited, for permission to use certain hitherto unpublished information concerning their respective wells.

He also wishes to express his thanks and appreciation to his colleagues, particularly Clare M. Clark, and to members of the Alberta Society of Petroleum Geologists, for their valuable assistance.

NOMENCLATURE

The sediments comprising these formations were early described by Dawson,[1] who noted that those strata conformably below the Pierre shale and above the "Lower Dark shales" (later shown to be Pakowki and not Colorado shale) consisted of a pale-colored upper part and a sombre-colored lower part.

Several years later Stanton and Hatcher[2] traced the Judith River formation and the strata associated with it in Montana northward across the International Boundary into Alberta. By this means it was proved that the Judith River beds (undivided in Montana) and the Pale and Sombre beds of Canada are equivalent. Both are overlain by the marine Bearpaw shale (Upper Pierre) and underlain by the marine Claggett (Pakowki) formation.

Dowling[3] later named the pale-colored very arenaceous strata the Pale beds and the lower dark or sombre-colored argillaceous sediments the Foremost. These divisions were given the rank of formations and as such he mapped them separately in the southern plains of Alberta. He also defined the Belly River series as consisting of four formations, which in ascending order are: the Milk River sandstone, the Pakowki formation, the Pale beds, and the Foremost formation. These occupy that part of the column between the Colorado shale below and the Bearpaw shale above.

A recent discussion concerning the nomenclature of these strata is that by Williams and Dyer,[4] who would restrict and apply the term Belly River as a formation name to include only those sediments be-

[1]G. M. Dawson, "Report on the Country in the Vicinity of the Bow and Belly Rivers." *Geol. Survey of Canada Rept. of Progress, 1882-84* (1885), Pt. 4.

[2]T. W. Stanton and J. B. Hatcher, "Geology and Paleontology of the Judith River Beds," *U. S. Geol. Survey Bull. 257* (1905).

[3]D. B. Dowling, *Geol. Survey of Canada Summary Rept.* (1915); "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917).

[4]M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930), pp. 16 and 17.

tween the marine Pakowki and Bearpaw shales, which, they contend, was the original intention of Dawson. These authors class the Pale beds and Foremost as members of the Belly River formation.

It seems inadvisable to adopt this retroactive proposal of Williams and Dyer in regard to the restricted use of the term Belly River. Dowling[1] clearly defined this as the name for a specified series which on the plains can be separated into several formations. However, as it is not yet possible to subdivide these or equivalent sediments in the foothills region, it seems desirable to retain the series name. If a collective term is needed to designate those strata between the Bearpaw and Pakowki shales, it seems logical to use the term Judith River, which not only has priority but in addition would eliminate the confusion involved by changing the definition of the term Belly River. Although the Pale beds and Foremost strata are somewhat similar and the contact between them is gradational rather than abrupt, they are sufficiently different and distinct to permit them, in most places, to be recognized and differentiated in the field.

Since the time when Dowling described and mapped the Pale beds and Foremost strata, the use of these names for the respective formations has become somewhat firmly established in the literature. The foregoing reasons are deemed valid and sufficient authority to justify the continuance of the terms as formation names and as such they are used in this paper.[2]

DESCRIPTION OF FORMATIONS

Short descriptions of the Pale beds and the Foremost formation as they appear in exposed sections on the plains of southern Alberta will provide the reader with data which are necessary to the proper interpretation of the accompanying graphic sections, such as information con-

[1] *Op. cit.*

[2] Since this paper was submitted for publication the Geological Survey of Canada has issued *Summary Report, 1929*, Part B, (1930) *Pub. No. 2255*. This report was published subsequent to the frequently cited *Geol. Survey of Canada Memoir 163* (1930), *Pub. No. 2244*, by Williams and Dyer.

One of the papers in the *Geol. Survey of Canada Summary Report, 1929* (1930), *Pub. No. 2255*, is entitled "Oil and Gas Prospects in Central Saskatchewan," by P. S. Warren. The following quotation is from Warren's report, P. 41 B, "....the beds observed probably represent the Pale beds—the uppermost formation of the Belly River series...."

This later publication indicates that a difference of opinion exists among some of the Dominion geologists, who have worked in the western plains, regarding the nomenclature and rank of the stratigraphic units situated between the Bearpaw and Pakowki shales. The Geological Survey of Canada has evidently decided to follow the older and more firmly established practice of using the term Belly River to designate a stratigraphic series which is composed of several formations as originally defined by D. B. Dowling.

cerning minor structural features which as a rule can not be determined from the logs of widely separated wells.

FOREMOST FORMATION

These sediments consist chiefly of brackish-water, lagoonal deposits among which shales and shaly silts, with subordinate amounts of sandstone, predominate. All phases of these sediments exhibit lensing, which may occur in relatively short distances. The sandstones are generally gray, buff, or tawny brown; dark grays and browns predominate in the shales. On the whole, as these rocks contain variable amounts of colloidal material and are not well cemented or indurated, they do not resist erosion well. At some localities in southern Alberta the base of the Foremost is marked by the presence of a generally massive gray to tawny sandstone of variable thickness. Other components are small amounts of selenite, bentonite, and ironstone nodules and stringers. The ironstones ordinarily are a mixture of iron oxide and clay and have a light brown color. Another form of concretion is that composed of sandstone with calcareous cement. These differ in size from a few inches to several feet in diameter or length. Most of the sandstone ledges which stand out prominently on the sides of coulees or along streams, owe their resistance to a calcareous cement. Oyster shells are plentiful, particularly in the upper part of the formation, and commonly occur at

FIG. 1.—Foremost beds exposed along Lost River, Alberta, in T. 1, R. 4, W. of 4th Mer. (Photograph by Theodore A. Link.)

intervals through beds of poorly consolidated gray sandstone or as hard, tightly compressed coquina beds, some of them 3 feet or more in thickness.

The Foremost contains many coal or carbonaceous beds. Some of the most prominent of these are the McKay coal measures, ordinarily present near the base of the formation, and another, the Taber coal measures, is locally present at the top. These coal seams are variable in thickness, character, and position in the section, as well as in lateral distribution. Carbonaceous shales or coals grade in places from one to the other and in places either or both disappear entirely in relatively short distances.

Besides various species of *Ostrea*, the Foremost beds contain shark teeth, fish vertebrae, fragments of bone, plant remains, and other carbonaceous matter, plentiful remains of fresh- and brackish-water gastropods and pelecypods, and some marine forms. For a treatment of the paleontology of this formation and the Pale beds, the reader is referred to the recent publication of Williams and Dyer.[1]

PALE BEDS FORMATION

The sediments of this formation are of fresh-water origin and consist chiefly of gray and greenish gray sandstones, and shaly sandstones, with some darker shales. Light gray, rather massive, poorly consolidated sands containing much colloidal clay are characteristic. As a whole, the formation is poorly indurated and is very susceptible to erosion. Along coulees, stream courses, and other places of pronounced relief, slumping is common. On the larger exposed areas, bad-land topography, such as that near Red Deer River east of Steveville,[2] is developed in some places. Among the minor features are small mushroom-shaped, erosional remnants or "hoodoos," each with a cap of sandstone, ironstone, a glacial boulder, or other resistant rock. Among the softer strata are some hard sandstones which in places stand out as ledges from sides of coulees and stream courses. Some of the harder beds have current and ripple marks. Sandstone concretions of various sizes occur irregularly in the section. Most of the strata are very lenticular and, in places, both vertical and lateral changes occur in very short distances. Cross-bedding is extremely common and is one of the depositional characteristics.

[1] *Op. cit.*, p. 30.

[2] For some excellent pictures of the geological features and popular descriptions of the paleontology of the Pale beds (Belly River formation) at this locality, the reader is referred to an article by Barnum Brown, entitled "Hunting Big Game of Other Days," *National Geographic Magazine*, Vol. 35 (May, 1919), pp. 407-29.

FIG. 2.—Looking east at upper Pale beds exposed on north side of Little Bow River in southwest part of Sec. 31, T. 12, R. 19, W. of 4th Mer., Alberta.

Among the accessory materials are thin bands of bentonite, small amounts of selenite, calcareous nodules and concretions, and ironstone nodules, stringers, and bands. These ironstones are generally brown, hard, and many of them have irregular pitted surfaces. They consist of variable proportions of iron oxide, iron carbonate, and clay. Thin stringers and nodules of gray to tan impure calcareous matter ("lime"), which may have been deposited as chemical precipitates in fresh-water lakes, are also present.

The fossil pelecypods, the many reptilian remains at some localities, and the carbonaceous matter distributed through the column indicate that these are, for the most part, fresh-water deposits. A few brackish-water mollusks are found, particularly near the top, and these indicate a transitional phase to the marine strata above. The division between the Pale beds and the Foremost formation is discussed later.

Coal beds or carbonaceous shales are invariably present in the upper part of the formation and for practical purposes the highest coal or carbonaceous stratum is commonly taken as the top of the formation. These coal beds are known as the Lethbridge coal measures in that district. Conformably above the Pale beds is the black, marine Bearpaw shale. The change from the gray arenaceous coal-bearing sediments to the dark marine shales is ordinarily distinct.

DESCRIPTIONS OF WELL SECTIONS

The Pale beds and the Foremost formation contribute more areal surface to the geologic map of southern Alberta than any others. However, the writer knows of no place where a complete and unbroken section of either formation can be studied or measured, although there are many well-exposed partial sections. The most reliable, but indirect, measurements are those provided by the few deep wells which have penetrated the entire thickness of these beds. Two are present in the western part of the Cypress Hills on the east, and possibly there are not more than five adjacent to, but beyond, the western outcrops. Several others began only short distances below the top of the Pale beds and material from three of these, together with certain supplementary data, have also been used in the preparation of this paper.

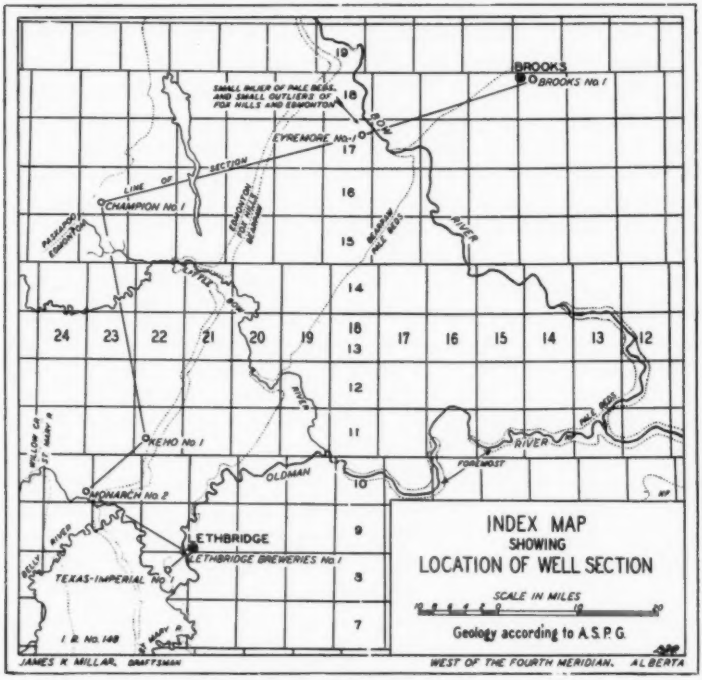

FIG. 3.—Index map of Lethbridge-Brooks area, showing locations of wells and areal geology.

All the wells from which the information for the accompanying sections was secured are located near the western limit of the Pale beds outcrops and, with their respective locations, are shown on the index map (Fig. 3). Most of these holes were sunk as deep tests for oil and gas. In every well, drills of the standard, cable-tool type were employed.

These bore holes are situated along an irregular northeast-southwest line, the ends of which are 65 miles apart. The line of section is on the northwest flank of the Belly River arch and is approximately parallel with the general strike of the formations.

The information used in the preparation of the sections was derived from examinations of the recovered rock samples. As the basic data are dependent on well cuttings, allowances must be made for possible inaccuracies in reported depths, differential resistance to abrasion, percentage recovery of the respective sediments, and for some unavoidable caving of formation. The personal element must also be considered, particularly as applied to the recognition and determination of the relative amounts of the constituent materials.

Texas Imperial No. 1.—This well, which is at the southwestern end of the section, begins in the Pale beds some distance below the top. A comparison of the log of this well with that of the near-by Breweries well suggests that about 65 feet of the highest Pale beds section is missing, thereby accounting for the fact that no coals of the Lethbridge measures were encountered. The remainder of the Pale beds section consists of gray and greenish gray shales and sandstones.

Of the 410 feet classed as Foremost sediments, dark gray shales with small amounts of sand predominate. In this well the lower part of the McKay coal measures is best developed. The basal stratum is a carbonaceous shale with only a small amount of sand.

Lethbridge Breweries No. 1.—The top of the Pale beds is marked by the well developed Lethbridge coal measures. The remainder of the 740 feet of this formation consists of gray and greenish gray alternating sandstones and shales.

To the Foremost formation has been allotted 410 feet of dark gray sediments consisting chiefly of shale with some subordinate amounts of sand. The lowest coals of this formation are distributed through a vertical distance slightly in excess of 100 feet. In this hole the upper members of these coal measures are the best developed. The base of the formation contains a considerable amount of sand.

Lethbridge City well (L. S. 14, Sec. 31, T. 8, R. 21, W. of 4th Mer.).—This well, which is situated about ½ mile from the Breweries well, en-

countered 299 feet of overburden, according to Dowling's[1] published log. Evidently all of the coal of the Lethbridge measures was entirely eroded at this location. A correlation of the log of this well with that of the near-by Breweries well indicates that approximately the upper 90 feet of Pale beds sediments is missing from the former. As the City well does not record any coal of the McKay horizon near the base of the Foremost formation, no correlation of this part of the section is attempted.

Monarch No. 2.—At the top of the Pale beds are the persistent Lethbridge coal measures. The thickness of this carbonaceous zone is much less in this well than it is in the others of this area. The 760 feet assigned to the Pale beds consists chiefly of gray shales and sandstones with considerable amounts of calcareous matter.

The lower 395 feet of section has been assigned to the Foremost formation. It consists of dark gray shale and sandstone with the coal seams in the lower part. The base is marked by a thin sandstone. The division between the Pale beds and the Foremost in this well is less distinct than in the others and the point of contact has been arbitrarily selected.

Keho No. 1.—The top of the Pale beds is marked by a very thin sandstone which is a few feet above the coal seams. The remainder of the 680 feet consists of alternating gray shales and gray to greenish gray sandstones. A little ironstone is present near the top and considerable amounts of calcareous matter and bentonite are distributed through the column.

The next 390 feet is classed as Foremost and consists almost entirely of dark gray, slightly sandy shale with considerable amounts of ironstone, fossil shells, and some bentonite with the coals of the McKay horizon near the base.

Champion No. 1.—The first 600 feet of strata below the Bearpaw shale has been classed as Pale beds. At the top of the formation are the ordinary coal seams and below these are a series of gray and greenish gray sands and shale containing some calcareous matter.

The 400 feet allotted to the Foremost formation consists almost entirely of dark gray sandy shale with some coal seams, notably near the top and bottom, and with a 10-foot bed of sand at the base. Thin ironstone and bentonite bands are also present.

Eyremore No. 1.—This well begins in a small inlier of Pale beds, a short distance below the top of that formation. A very reliable estimate

[1]D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917), p. 96.

concerning the amount and character of the eroded part is possible, as many test holes were drilled in the immediate area surrounding the deep well location. Most of these penetrated the lower part of the Bearpaw shale and some distance into the underlying formation.

At the top of the Pale beds is about 5 feet of light gray sandstone accompanied by a little shale. Then follows a 50-foot section of shale which here contains, as a rule, three or four coal seams. As shown by the graphic section, the lowest of these coal seams was encountered near the surface in the Eyremore well. Therefore it is evident that approximately the upper 45 feet of Pale beds has been eroded at this site.

Below the coal measures is 550 feet of gray and greenish gray sands, shales, and varying mixtures of these, together with some calcareous and here and there a little carbonacous material. The next 420 feet of section is dominantly medium to dark gray shales with coal beds near the top and bottom. Intervening carbonaceous matter, bentonite, and ironstone are also present, and a 10-foot sand marks the base. According to this information the Pale beds would have a calculated thickness of 605 feet. The lower 420 feet of strata has been assigned to the Foremost formation.

Brooks No. 1.—This well is 22 miles from Eyremore No. 1 and is at the northeastern end of the section. As at Eyremore, this well began some distance below the top of the Pale beds. The upper 470 feet consists chiefly of gray and greenish gray sands and sandy shales. The next 375 feet consists almost entirely of dark gray and brown shales with coal beds near the top and bottom.

A correlation of the log of this well with that of Eyremore No. 1 suggests that as much as 135 feet of upper Pale beds may have been present but subsequently was eroded at the Brooks locality. The complete section of the Pale beds would have an estimated thickness of about 605 feet. The lower 375 feet of strata is classed as Foremost.

CORRELATION OF WELL SECTIONS

Pale beds.—The top of the Pale beds is marked by the Lethbridge coal horizon which, as a rule, occupies 50 or 60 feet of section. The sediments below these coals consist chiefly of gray and greenish gray sandstones and shales with variable amounts of calcareous, carbonaceous, and bentonitic matter.

With the exception of the coal series at the top, it is impossible to correlate with certainty any of the strata in the entire group of sections. Correlations of individual strata even between adjacent wells are ex-

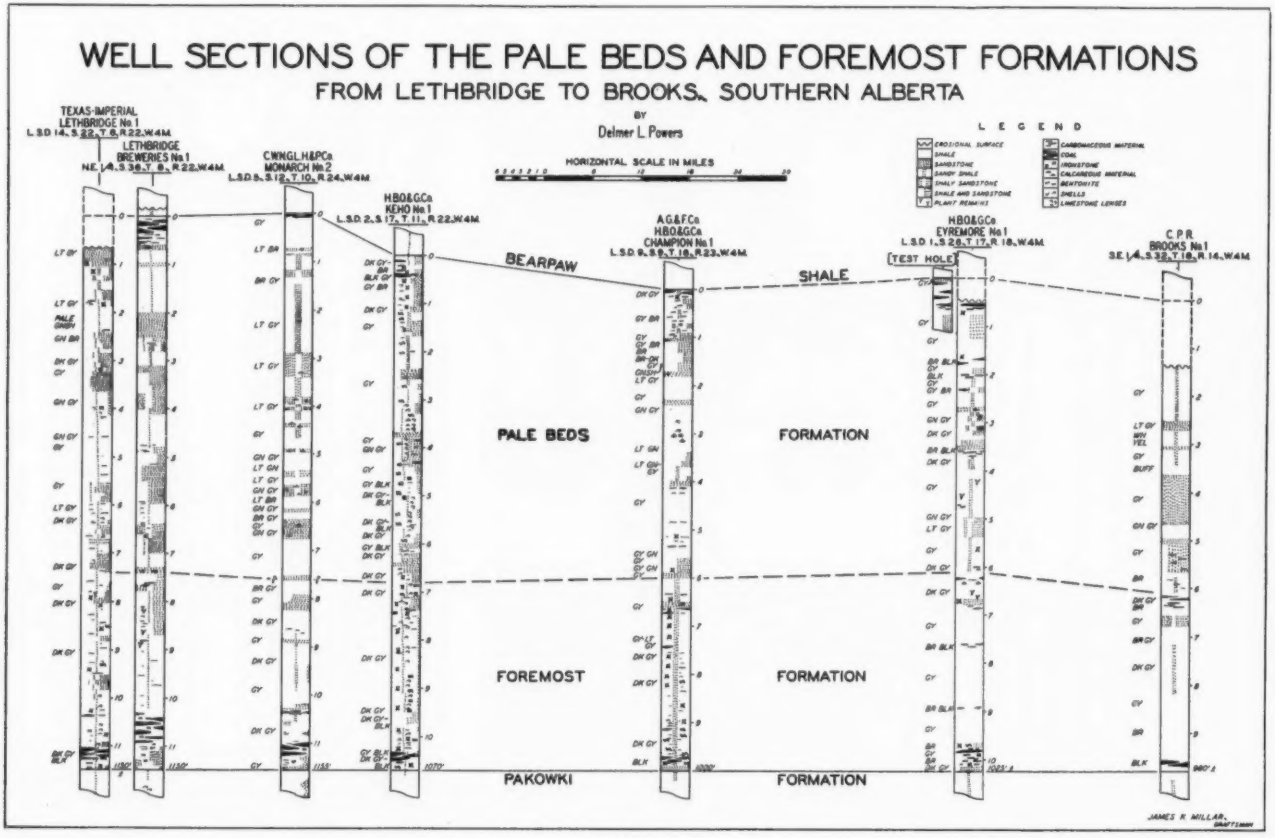
WELL SECTIONS OF THE PALE BEDS AND FOREMOST FORMATIONS
FROM LETHBRIDGE TO BROOKS, SOUTHERN ALBERTA
BY
Delmer L. Powers
HORIZONTAL SCALE IN MILES
LEGEND
EROSIONAL SURFACE
SHALE
SANDSTONE
SANDY SHALE
SHALY SANDSTONE
SHALE AND SANDSTONE
PLANT REMAINS
CARBONACEOUS MATERIAL
COAL
IRONSTONE
CALCAREOUS MATERIAL
BENTONITE
SHELLS
LIMESTONE LENSES
TEXAS-IMPERIAL LETHBRIDGE No. 1
L.S.D. 14, S. 22, T. 8, R. 22, W.4M.
LETHBRIDGE BREWERIES No. 1
N.E. 1/4, S. 36, T. 8, R. 22, W.4M.
C.W.N.G.L. H&PCo MONARCH No. 2
L.S.D. 5, S. 12, T. 10, R. 24, W.4M.
H.B.O.&G.Co KEHO No. 1
L.S.D. 2, S. 17, T. 11, R. 22, W.4M.
A.G.&F.Co H.B.O.&G.Co CHAMPION No. 1
L.S.D. 9, S. 9, T. 18, R. 23, W.4M.
H.B.O.&G.Co EYREMORE No. 1
L.S.D. 1, S. 28, T. 17, R. 18, W.4M.
[TEST HOLE]
C.P.R. BROOKS No. 1
S.E. 1/4, S. 32, T. 18, R. 14, W.4M.
BEARPAW
SHALE
FORMATION
PALE BEDS
FOREMOST
FORMATION
PAKOWKI
FORMATION
JAMES R. MILLAR, DRAFTSMAN

FIG. 4

tremely hazardous. Although some beds seem to be represented in adjacent sections, there are as many others that evidently have no corresponding equivalents. This tends to cast considerable doubt on the apparent correlations and suggests that possibly the correlated beds are only lenses which coincide in the sections, rather than representatives of continuous strata.

The well logs indicate that in general the Pale beds in the southwest contain considerably more sand and less shale and colloidal material than they do in the northeast.

It is also a noteworthy fact that the formation is thicker in the southwest and thinner in the northeast. In the Lethbridge district the

FIG. 5.—Looking northeast across Oldman River at upper Foremost strata exposed in SE. ¼, Sec. 18, T. 10, R. 16, W. of 4th Mer., near Taber, Alberta. Taber coal seam may be seen about half-way up exposed section.

thickness is 740 feet and at the Eyremore well it is 605 feet. This represents a thinning of 135 feet in 57 miles, or an average decrease of 2.4 feet per mile in a northeasterly direction.

The coal series at the top of the formation occupies a restricted part of the section and has a wide lateral distribution; hence it is very dependable for correlation.

Foremost.—In nearly half the wells a coal series, which is probably the equivalent of the Taber horizon, is present at or near the top of the formation. In contrast to the materials of the overlying strata the Foremost beds are composed chiefly of dark gray shales with subordinate

amounts of sand. At intervals throughout the section are found carbonaceous material and some ironstone, fossil shells, and other accessory materials. At or near the base of the Foremost is the widespread McKay coal horizon. The greatest development of coal does not invariably occur at the same corresponding position but may be distributed through as much as 120 feet of section. The main coal beds of this series are nearly everywhere accompanied by prominent seams of bentonite. Four of the well sections show sand beds at the base of the formation. However, this sandstone is not laterally persistent and its thickness is not uniform.

The Foremost sediments, as a whole, are very lenticular and the most definite horizon that can be correlated with certainty throughout the entire group of wells is the basal coal measures.

As shown by the sections, the thickness of the formation is generally uniform and does not vary greatly from 400 feet within the area considered. The greatest change occurs between the Eyremore and Brooks wells, where thinning toward the east amounts to 45 feet in the 22 miles.

The contact with the Pale beds is gradational rather than abrupt and can not be used as a horizon for detailed mapping. However, for general correlation, it can, as a rule, be fixed within workable limits.

With reference to the upper limit of the Foremost beds, Dowling[1] states:

> The top of the formation is placed generally as a certain coal seam that in various places is important enough to be mined. As the seam is not confined to any exact position in the upper part of the formation this horizon marker is not strictly the top of the formation and the apparent thickness of the division may for this reason appear variable.

There is a decided change from the dark gray and tawny coal-bearing shales and sandstones of the Foremost to the lighter gray and greenish gray, highly arenaceous sediments of the Pale beds, and these distinctions are probably more dependable than the presence or absence of a minable coal seam.

The coal measures near the base of the Foremost, although somewhat variable in their position of greatest development in the section, are widely distributed and are very useful as a horizon for correlation.

REGIONAL CHARACTERISTICS

Throughout much of the foothills belt of southern Alberta the Belly River formation has a thickness of about 2,000 feet. These sediments

[1] *Op. cit.*, p. 37.

consist largely of fresh- and brackish-water deposits of light greenish clays and shales, gray and greenish thin-bedded and massive, coarse-grained sandstones, and some conglomeratic sandstones. Most of these sediments are the western equivalents of the Pale beds and the Foremost formation. Toward the east the sediments become finer-grained, and continuous beds of conglomerates are absent in the plains.

The Pale beds and the Foremost formation (Judith River beds) thin considerably from west to east. The isopach map (Fig. 6) showing

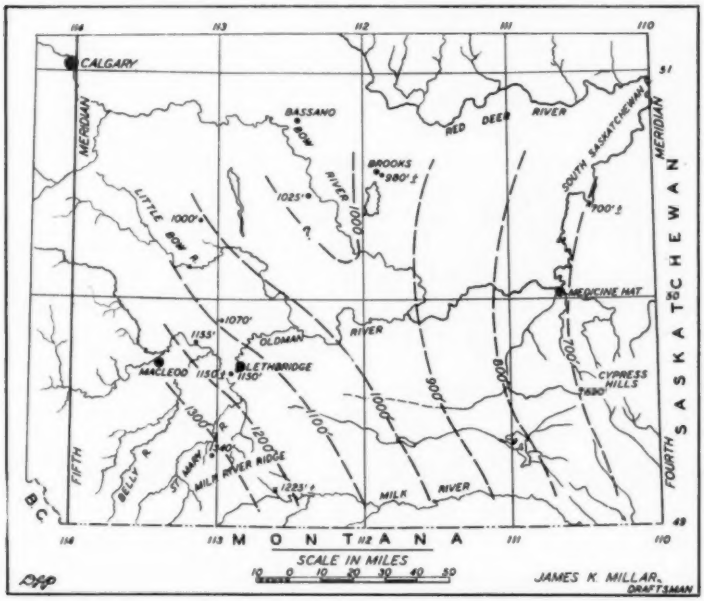

FIG. 6.—Generalized isopach map of combined Pale beds and Foremost formation in southern Alberta.

the combined thickness of the two formations, indicates that a thinning of about 600 feet occurs in the distance of 125 miles from Macleod to Medicine Hat. This represents an average decrease in thickness of approximately 5 feet per mile.

GEOLOGIC HISTORY

Foremost.—Foremost time was inaugurated in this area by the gradual recession of the Pakowki (Claggett) sea. This is marked in

some localities by what is interpreted as a thin beach sand, but at other places this sand is not present and the transition from the marine shale is indicated by poorly sorted silts and a thick series of coals and other carbonaceous material. These facts suggest the presence of a broad, low, and relatively flat plain, the seaward edge of which was extremely irregular. This swampy coastal area evidently supported a dense vegetation, much of which became submerged, thereby escaping oxidation. This was then covered by sediments and finally carbonized. Across this low, marshy area, sluggish streams, which had their sources in some western land mass, meandered and carried their fine sediments eastward toward the shallow epicontinental sea. Lakes, lagoons, and embayments were undoubtedly numerous and these probably provided the means by which contemporaneous sediments were deposited under fresh-water, brackish-water, and marine conditions in contiguous localities.

Some changes of minor importance probably affected the drainage at times, for here and there in the section considerable amounts of sand are present. Although much carbonaceous material is present in the sediments, there was a return to more favorable coal-forming conditions in a part of the area, near the end of this period of deposition.

The evidence does not indicate that any decided uplift occurred during this time, but on the contrary it is more probable that the sea was forced to retreat eastward by the advance of the wide front of coalescing deltas. The rates of subsidence and sedimentation seem to have been approximately the same, thereby maintaining the plane of deposition at or near sea-level throughout Foremost time.

Pale beds.—The landward side of the broad coastal plain was subsequently raised so that the drainage slope was materially increased. This marked the beginning of Pale beds time. The steeper gradient increased the transporting power of the streams and much sand was carried along with the finer materials. Alternations of shale and sandstone indicate somewhat erratic conditions of deposition.

A noteworthy part of the Pale beds has a greenish gray color which is probably due to the presence of ferrous iron compounds. This suggests that conditions prevailing in the contributory land mass were not favorable to oxidation or that erosion was very rapid.

The tilting of the coastal plain probably caused the disappearance of the larger lagoons and deep embayments and resulted in a less sinuous coast line.

The character and composition of the poorly sorted sediments and the very lenticular form of the strata indicate that for the most part they were deposited under fresh-water conditions in lakes and deltas.

Carbonaceous material is present here and there, but general absence of coals in the greater part of the section may have been caused both by a decrease in the amount of vegetation and by the lack of favorable conditions for accumulation and preservation.

Nearly at the close of the age, the landward side of the coastal region evidently sank, thereby resulting in a broad, flat plain slightly above sea-level. Swamp conditions with dense vegetation were reëstablished, which again resulted in the wide deposition of a series of coal beds.

The final advance of the Pierre (Bearpaw) sea is marked at some localities by only a very thin sandy transition zone. The lack of prominent littoral deposits throughout a wide area indicates an extensive submergence of low lands. This closed the Pale beds epoch.

AGE OF FORMATIONS

Dowling,[1] in describing the geology of the southern part of the province, lists and illustrates by means of excellent plates many Pale beds and Foremost fossils.

Williams and Dyer,[2] in their treatment of the geology of this same area, discuss the paleontology and correlations of the Pale beds and the Foremost at some length. They also present extensive lists of fossils which have been described from the formations.

Perhaps the best evidence for fixing the age of the Pale beds and Foremost sediments is the fact that they are situated in the stratigraphic column between the Pakowki and Bearpaw shales, both of which contain invertebrate marine faunas of Montana Cretaceous age.

SUMMARY AND CONCLUSIONS

1. The terms Pale beds and Foremost have been clearly defined and applied to mappable lithologic units in southern Alberta for many years. These names have also become firmly established in the literature and should be retained as names for the respective formations.

2. The Foremost formation consists largely of brackish-water, lagoonal deposits, among which dark gray shales with considerable amounts of carbonaceous matter predominate.

The Pale beds consist chiefly of fresh-water deltaic deposits of light gray shales and sandstones with some carbonaceous material. The amount of sand in the section decreases from southwest to northeast.

[1] D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917).

[2] M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930).

3. Persistent coal measures at the base of the Foremost formation and at the top of the Pale beds are very useful for correlation (Fig. 4).

4. No complete exposed sections of either the Pale beds or the Foremost formation are known in southern Alberta. Therefore, the most accurate information regarding thicknesses is provided by some wells that have entirely penetrated the formations. The thickness of the Pale beds near Lethbridge is 740 feet and at Eyremore, 57 miles northeast, is 605 feet. The thickness of the Foremost in most of this area is about 400 feet, but a considerable thinning northeastward probably occurs between Eyremore and Brooks.

5. The combined thickness of the two formations also decreases from west to east. This thinning amounts to about 600 feet in a distance of 125 miles (Fig. 6). Coarse, conglomeratic sandstones which are present in the Belly River formation of the foothills are absent in the equivalent sediments of the plains on the east. These variations in the thickness and composition of the formations indicate that the source of the sediments was in some land mass west of the epicontinental sea.

6. As the Pale beds and the Foremost formation occupy that part of the column between two marine formations which contain Montana Cretaceous fossils, they necessarily are of the same age.

SEDIMENTS OF MONTANA AGE IN MILK RIVER RIDGE REGION, ALBERTA[1]

B. F. HAKE[2] and CARL C. ADDISON[3]
Calgary, Alberta

ABSTRACT

In this paper are presented the detailed stratigraphy of the marine Bearpaw shale, 690 feet thick, and the underlying continental Pale beds and the Foremost formation, which have a combined thickness of 1,225 feet. From surface information and well samples these formations are subdivided into several zones which permit detailed correlations.

These sediments record that the western shore line of the Montana sea receded before the advance of the continental deposits which compose the Pale beds and the Foremost. A subsequent westward marine transgression, probably the result of crustal warping, is recorded by the Bearpaw shale.

INTRODUCTION

The data presented in this paper were collected in an area which extends along the southern flank of the Milk River Ridge and northward into the drainage system of Pothole Creek (Fig. 1).

The formations here described underlie the Fox Hills sandstone and are underlain by the Pakowki shale. They are divided into three formations. The highest of these is a marine shale known as the Bearpaw formation. Below the Bearpaw is a series of continental sediments,[4] of which the upper part is named the Pale beds and the lower the Foremost formation.

In the opinion of the writers the term "Pale beds" is not satisfactory as a formation name, but since it has been widely used in the geologic literature of Alberta, and also because it is difficult to choose a satisfactory type locality for the formation, the established terminology is here employed.

[1]Read before the Alberta Society of Petroleum Geologists at the Calgary meeting, January 17, 1931. Manuscript received, May 18, 1931. Published by permission of Nordon Corporation, Ltd.

[2]Chief geologist, Nordon Corporation, Ltd.

[3]Geologist, Nordon Corporation, Ltd.

[4]D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917).

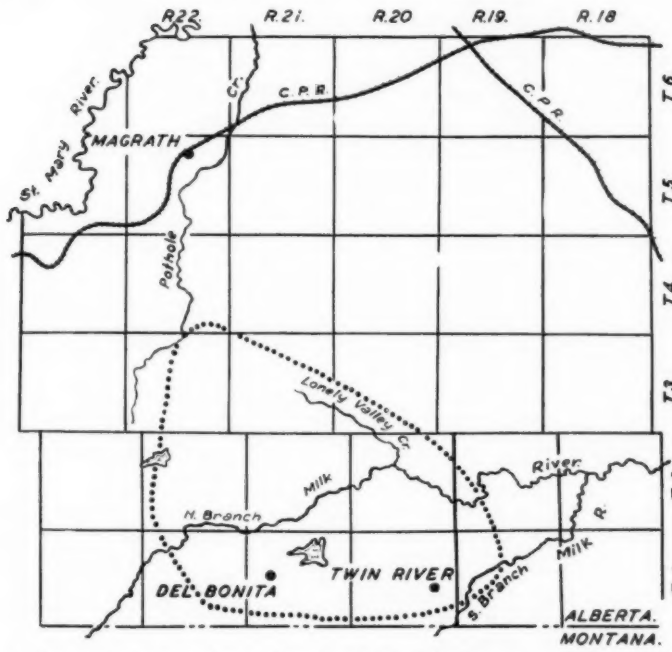

FIG. 1.—Index map of part of southern Alberta showing area considered. Width of each township and range, approximately 6 miles.

The equivalents of these formations have been mapped in Montana on both the eastern and western flanks of the Sweetgrass arch. In both of these areas the Bearpaw shales are recognized and are so named. The equivalent of the combined Pale beds and Foremost formation in Montana is the Judith River formation. The Two Medicine formation of the western flank of the Sweetgrass arch includes the equivalents of the Pale beds, the Foremost, and a considerable additional thickness of underlying sediments. These relationships are shown in Figure 2.

The information here presented is derived from two sources, surface observations and examination of well samples. The combination of these two methods of investigation is necessitated in the plains of Alberta because in large areas the significant rocks are concealed by glacial drift. About two-thirds of the data were obtained by examinations of samples collected from wells drilled to obtain structural data. Churn drills and a jetting machine were used in this work. A sample was taken

	WESTERN MONTANA	SOUTHERN ALBERTA	EASTERN MONTANA
UPPER CRETACEOUS	HORSETHIEF	FOX HILLS	FOX HILLS
	BEARPAW	BEARPAW	BEARPAW
MONTANA	TWO MEDICINE	PALE BEDS	JUDITH RIVER
		FOREMOST	
		PAKOWKI	CLAGGETT
		UPPER MILK RIVER	EAGLE
	VIRGELLE	LOWER MILK RIVER	

FIG. 2—Correlation chart of Montana Cretaceous formations in Alberta and Montana.

from each 4 feet of hole, and the utmost care exercised in collecting and examining the cuttings. The conclusions here presented are the result of both microscopic and megascopic examination of the samples.

The remainder of the information is the result of plane-table surveys. The stratigraphic thicknesses computed by this method are believed to have a somewhat lower degree of accuracy than those derived from well logs, on account of the discontinuity of outcrops which necessitated the projection of dips.

It is estimated that thicknesses of individual members of formations are accurate within 4 feet where the data were derived from wells, but where obtained by surface measurement it is considered that there may be a maximum error of 10 per cent.

ACKNOWLEDGMENTS

The writers are indebted to the Nordon Corporation, Limited, for the opportunity to collect and for permission to publish most of this information. The description of the basal beds of the Foremost formation is included herewith by permission of J. S. Irwin, of the Parco Oil Company, Limited. The surface information was in part collected by S. B. Jones and G. E. Wheeler, whose contributions are gratefully acknowledged.

DESCRIPTION OF FORMATIONS

Foremost formation.—The Foremost formation is known in this area only from well samples. By correlation of drill holes it is calculated that the formation has a local thickness of 350 feet. The lower of two beds of fairly well sorted subangular sand (Fig. 3) is taken as the basal member of the formation. These sands are regarded as the record of beach conditions during the regression of the sea in which the underlying Pakowki shale was deposited.

The Foremost is a series of very carbonaceous shales with plentiful invertebrate fossils, with seams of bentonitic clay, and many thin lenticular sandstones. The sands are uniformly fine and poorly sorted;

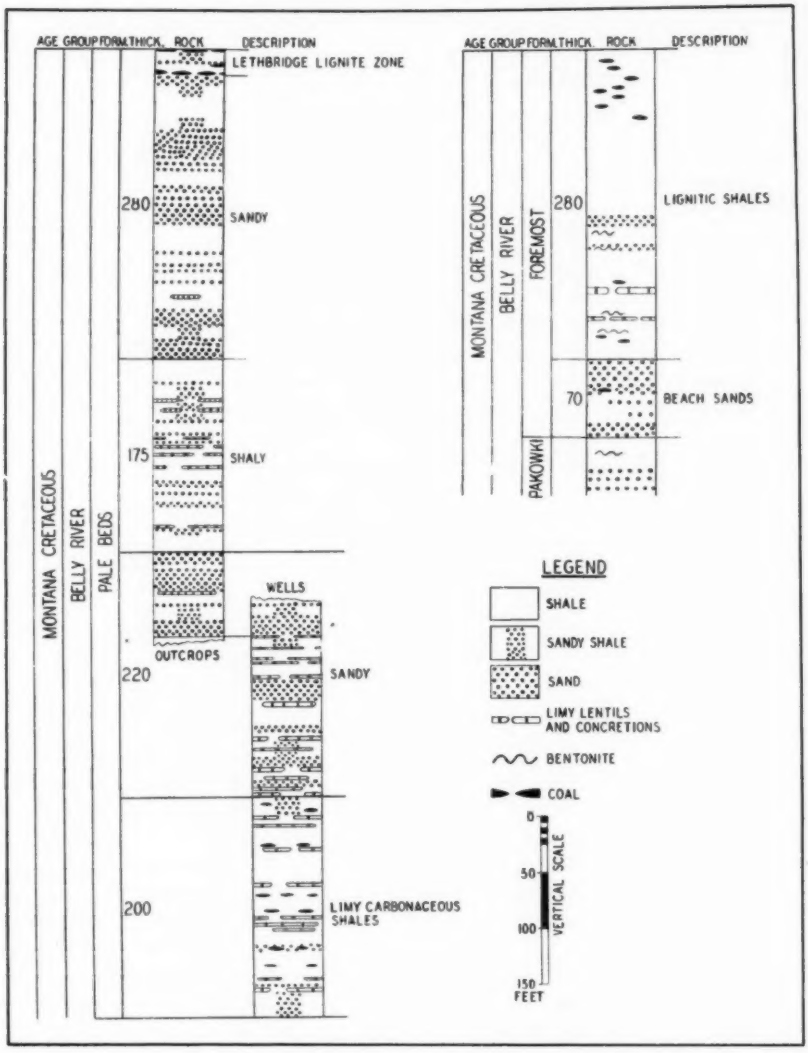

FIG. 3.—Columnar section of Pale beds and Foremost formation in Milk River Ridge region, Alberta.

the shales in most places contain notable amounts of fine silt. The greatest observed thickness of a single sandstone is 30 feet. A few concretions or lentils of limestone have been encountered, but these do not seem to be either plentiful or continuous. The plant fragments contained in these sediments, though generally carbonized, are locally replaced by pyrite. The lower part of the formation is more sandy than the upper.

The separation between the Foremost and the overlying Pale beds was conceived by earlier workers to be a separation between lignitic beds below and non-lignitic beds above. Dowling[1] says:

> The top of the [Foremost] formation is placed generally as a certain coal seam which in various places is important enough to be mined. As the seam is not confined to any exact position in the upper part of the formation, this horizon marker is not strictly the top of the formation, and the apparent thickness may for this reason appear variable.

He adds in a later paragraph:

> In the Lethbridge well section there is about 350 feet of beds which possibly should be included in the formation; but at Taber, where the section is much more definite, the thickness is only 300 feet at most.

In a later publication, however, Dowling[2] and others interpret the log of a well drilled at Taber as demonstrating that the Foremost formation has a local thickness of 326 feet.

In the wells which yielded the data used by the writers, the top of the Foremost formation is placed at a point above which the sediments are chiefly light-colored sands and clays with many beds and stringers of fresh-water limestone, below which the beds are notably fine-grained and dark, contain much lignite, and are notably lacking in lime content. This method of separation gives the Foremost formation a thickness in the Milk River Ridge region of 350 feet, comparing favorably with the foregoing figures.

Pale beds.—The total thickness of sediments here assigned to the Pale beds is 875 feet. These rocks are chiefly gray to green sandstones and shales, with limestone lentils and nodules (Fig. 3). Plant impressions and small fragments of carbonized wood are present in some strata, but the series as a whole is not very carbonaceous. Bones of vertebrates, shark teeth, and shells were found in the outcrops of the formation, and invertebrate fossils were present in considerable numbers in many of the well samples.

[1] *Op. cit.*, p 37.

[2] D. B. Dowling, S. E. Slipper, and F. H. McLearn, "Investigations in the Gas and Oil Fields of Alberta, Saskatchewan and Manitoba," *Geol. Survey of Canada Mem. 116* (1919).

The lower 350 feet of the Pale beds is not exposed along the North Branch of Milk River, but is known to the writers from drill holes. This part of the section consists of alternating sandstones and shales, with a few thin limestones. The exposed part of the formation, 525 feet in thickness, was measured by the writers along the course of the North Branch of Milk River in parts of T. 2, R. 19, 20, and 21, W. of 4th Mer. It consists of cross-bedded sandstones and light gray shales, with many thin limestones.

The surface rocks of this area are mapped as St. Mary River formation on the Calgary Sheet, Geologic Map 204 A, Geological Survey of Canada. The writers are obliged to disagree with this representation, as they have confirmed the opinion held by Dawson and McConnell,[1] who stated that the rocks which crop out along this part of the North Branch of Milk River "belong to the pale upper portion of the Belly River series and underlie the Pierre shales." The contact of the Pale beds and the overlying Bearpaw is exposed on the north bank of Milk River near the north line of Sec. 3, T. 2, R. 21, W. of 4th Mer., in which locality the contact dips southwestward at the rate of about 150 feet per mile. No Bearpaw shale is known to the writers at any point in Alberta along Milk River east of that locality. Moreover, the holes drilled under their supervision have demonstrated that the Bearpaw is not present as shown on Map 204 A in Range 20, between the North Branch and the South Branch of Milk River.

The formation can be subdivided into four distinct zones. The lowest is a shale zone 200 feet thick, bearing many thin limestones but only a few sandstones, and is characterized by the occurrence of thin carbonaceous beds which decrease in number, thickness, and carbon content from bottom to top. Above the lowest is a zone about 220 feet in thickness, also consisting of alternating sandstones, shales, and thin limestones. It is characterized, however, by the presence of massive sandstones and by the absence of lignitic beds. The upper 80 feet of this zone is exposed on the North Branch of Milk River.

The upper 455 feet of the formation is divided into two zones. The lower, 175 feet thick, is predominantly shaly and contains plentiful thin limestones. The upper zone has a thickness of 280 feet and contains more sandstones than shales, whereas limestones are almost lacking.

Almost one-fourth of the exposed section of Pale beds consists of light gray, lenticular sandstones. These are fine-grained, ill-sorted, and in the

[1] G. M. Dawson and R. G. McConnell, "Report on the Region in the Vicinity of the Bow and Belly Rivers, North-West Territories," *Geol. and Nat. Hist. Survey of Canada* (1884), p. 37-C.

main poorly cemented. They occur in beds ranging from a few inches to 6 or 8 feet in thickness. Contemporaneous sandstone conglomerates bearing fragments and pellets of shale occur at intervals throughout the section.

The shales, which constitute the bulk of the remainder of the exposed section, range from pure clay shales to sandy shales and siltstones, and do not crop out extensively. Colors range from light greenish gray to dark gray and purple, but light colors predominate. Weathering obscures the bedding of the shales and some outcrops are made white by a chemical efflorescence on the surface.

Interstratified with both shales and sandstones are many nodular limestones, which are regarded as of fresh-water origin. Generally these beds are thin, their average thickness being approximately 6 inches, but locally they attain thicknesses of 3 or 4 feet. Although they are undoubtedly lenticular, some of these limestones show a distinct tendency to persist laterally, a few localities being known to the writers where individual thin outcropping beds can be traced for distances of nearly ½ mile. The limestone composing these stringers is gray when freshly broken, but commonly weathers to deep reddish brown. Many of them have an almost flinty hardness and as a result crop out in weathered cuts and grass-covered hill slopes where no other exposures occur. Carbonaceous material is scarce in the exposed part of the formation.

The Lethbridge coal zone, recognized as marking the top of the Pale beds in southern Alberta, is represented on the North Branch of Milk River by a zone of sandy and carbonaceous shales and thin lignites. This zone crops out in Sec. 3, T. 2, R. 21, W. of 4th Mer. The exposure was examined by the junior writer and S. B. Jones, and the following section measured.

	Feet	Inches
Bearpaw Shale		
Dark gray, uniform, very slightly sandy shale	8	0
Sandy, very glauconitic shale, weathering yellow	2	0
Dark gray, sandy, micaceous shale. Bedding indistinct. Plant fossils in base	15	0
Hard, gray, fine-grained sandstone, weathering yellow. Plant remains		3
Pale Beds		
Black, very lignitic shale, sandy at top	7	0
Gray, fine-grained sandstone, weathering yellow. Plant fossils		6
Shaly sandstone, weathering yellow	1	0
Gray shale	1	0
Black, very carbonaceous paper shale. Plant remains	3	6
Bone-gray, thinly laminated cross-bedded sandstone	4	0
Dark gray shale, bearing plant remains	2	6
Bone-gray, thinly laminated, cross-bedded sandstone with carbonacous shale breaks	3	8

Test wells which penetrated the contact in two localities at distances ranging from 5 to 8 miles from the exposures described in the foregoing section revealed very similar sequences. In all of the three localities where the contact was studied a sandy glauconitic bed occurs approximately 20 feet above the highest lignitic bed.

Bearpaw shale.—The Bearpaw shale crops out at a few localities within this area and has been recognized southward far beyond the International Boundary and northward as far as Red Deer River. In the Milk River Ridge area a maximum thickness of 690 feet is calculated for the Bearpaw from test-well correlations. Some holes indicate less thicknesses for the formation, but the reasons for these variations are not yet evident.

The Bearpaw formation may be described as consisting throughout of uniform dark gray fossiliferous shale, but variations from pure clay shale to siltstone and sandy shale occur. Bentonitic seams are also numerous. The generalized sequence is shown in Figure 4.

Above the 20-foot sandy zone which constitutes the base of the formation there is a thickness of 140 feet of gray shale without any distinguishing characteristics. It is sparingly fossiliferous. At the top of this zone is a bentonite seam which has indications of being persistent. The 80 feet of shale immediately above this bentonite is locally sandy but seems to contain no persistent sand strata.

Test-well correlations show that the persistent silty and sandy beds are restricted to a zone about 150 feet thick, the base of which lies approximately 240 feet above the base of the formation. This zone was found to be continuous between two localities 10 miles apart, but other sandy members of the formation are too lenticular to be depended on for more than local correlations. All of the samples from the sandy and silty beds contained more or less glauconite.

Bentonite characterizes the upper half of the Bearpaw formation. Many of the beds seem to be discontinuous and erratic. Several individual bentonite beds were found to be continuous within the area of a single drilling project. A very bentonitic zone, 16 feet thick, immediately above the most persistent silty horizon, and maintaining a seemingly uniform position with respect to the top and bottom of the formation, was identified in nine out of ten holes, although the wells were drilled in two groups 10 miles apart.

Limy concretions or stringers are distributed throughout the section. In one group of holes these concretions were notably more plentiful in a zone about 75 feet thick and 108 feet below the top of the formation.

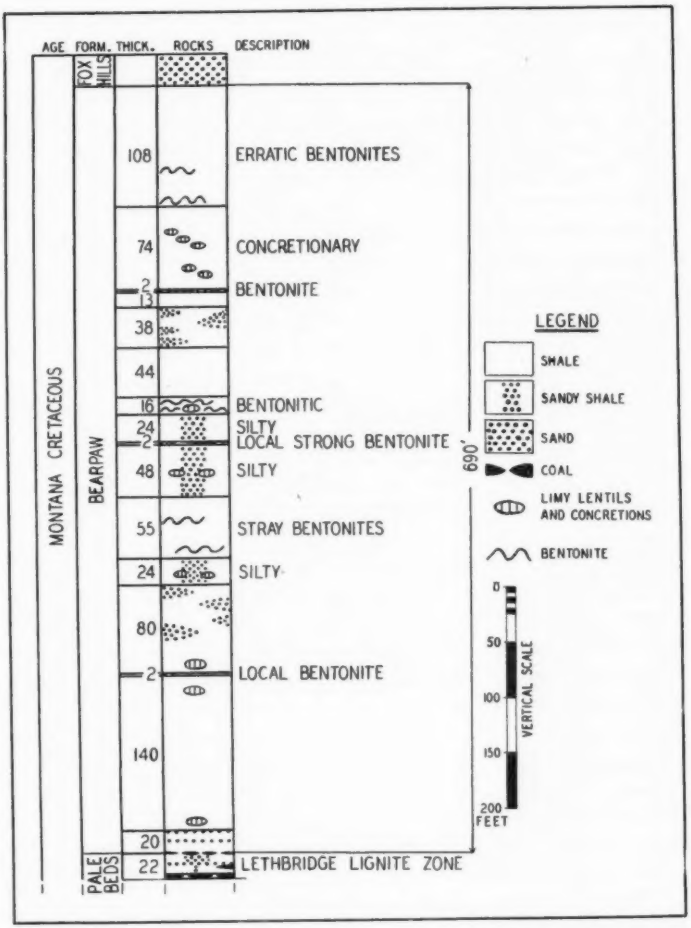

FIG. 4.—Columnar section of Bearpaw formation in Milk River Ridge region, Alberta.

The upper 108 feet of the formation consists of uniform dark gray shale with some fossils and many erratic unimportant bentonites. The contact with the overlying Fox Hills sandstone is sharp.

HISTORICAL GEOLOGY

The history of Foremost time in this area begins with the recession of the Pakowki (Claggett) sea. That the withdrawal of these marine waters was an oscillatory process is shown by the presence of two distinct sands separated by a thickness of slightly carbonaceous shale. During Foremost time the drainage systems of the coastal plain were incapable of carrying any coarse sediments or of effectively sorting those which were deposited. The terrain must have been almost flat, very poorly drained, and nearly covered by rank vegetation. Estuaries and shallow embayments probably extended far inland in some places, resulting in simultaneous deposition of fresh- and salt-water deposits in adjacent areas.

It seems probable that Foremost time was not inaugurated by tectonic uplift, but that the Pakowki sea was driven eastward by an advancing fringe of coalescing deltas, while regional subsidence kept approximate pace with deposition, thus maintaining a broad coastal plain approximately at sea-level, while 350 feet of sediments were there deposited.

During the deposition of the Pale beds, the plain was raised somewhat above sea-level so that the drainage and aeration of the soil were improved, and far less carbonaceous matter was preserved. Probably the cover of vegetation became less dense. The streams of this terrain were at first very sluggish, for the lower 200 feet of sediments of the Pale beds consists of shales and fine silts, not materially coarser than those of the Foremost.

Subsequently for a time the streams had a notably increased transporting power, for more than 50 per cent of the succeeding 220 feet of sediments are massive sandstones. During this time the terrain was much better drained than before, as the deposition of coal became sporadic and finally almost ceased.

The succeeding 175 feet of sediments record a time when the streams once more became sluggish and deposited chiefly mud and silt. However, coal-swamp conditions were not generally reëstablished in the area at this time, for the sediments of this part of the column do not contain much carbonaceous material.

During late Pale beds time the land was so well drained that organic matter generally became oxidized rather than carbonized. During

this time 280 feet of sediments accumulated which differ from those on which they rest only in that they contain less carbon and a greater proportion of sand. It was not until immediately before the advance of the Bearpaw sea that extensive coal swamps were again established.

The wide distribution of the thin series of lignitic sediments which marks the top of the Pale beds indicates that the terrain must have been exceedingly flat in a very large area. This sudden recurrence of widespread swamp conditions strongly suggests that the region was tilted westward and that the effectiveness of the drainage was thereby destroyed.

The advance of the Bearpaw sea is recorded only by a thin and insignificant bed of beach sand. This absence of important littoral deposits at the base of the Bearpaw shows that the region was suddenly inundated by marine waters, probably as a result of subsidence.

The Bearpaw shale is a record of remarkably uniform marine conditions during a considerable time, which ended with the retreat of the Bearpaw sea and deposition of the beach sand of the Fox Hills formation.

BEARPAW SHALE AND CONTIGUOUS FORMATIONS IN LETHBRIDGE AREA, ALBERTA[1]

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Calgary, Alberta

ABSTRACT

The Bearpaw shale of the Lethbridge area is 726 feet thick. It contains at least twenty-two bentonite beds, three distinct sandstone phases, which have been named for local usage, a glauconite sand, and two zones with exceptional profusion of fossils. The overlying Fox Hills sandstone has a thickness of 142 feet, and consists primarily of one unbroken sequence of coarse, massive, greenish sandstone which weathers buff, with an *Ostrea* coquina near the top. The Lethbridge coal measures of the upper Belly River series contain several coal seams, two of which are commercial. The top is marked by a thin, brown-weathering sandstone and locally an *Ostrea* coquina is found above the top coal bed. Descriptions of these formations, with stratigraphic columns and a brief historical sketch, are submitted.

INTRODUCTION AND ACKNOWLEDGMENTS

The object of this discussion is to present a detailed stratigraphic column of the Bearpaw shale, the overlying Fox Hills sandstone, and the underlying coal measures of the upper Belly River series. The stratigraphic column, as presented in this paper, was compiled from data obtained along Oldman and St. Mary rivers and their tributaries, and from several diamond-core drill holes sunk by the Commonwealth Petroleum Company, Limited, in the Blood Indian Reserve (Fig. 1). With permission of Senator E. Michener, president of the Commonwealth Petroleum Company, Limited, the results of the diamond-drill holes, as interpreted by the writers, are submitted. The coöperation of Harry Inglis, consulting engineer for this company, is also acknowledged with thanks.

LETHBRIDGE COAL MEASURES

The change from the light or pale-colored sandstones and grayish shales of the upper part of the Belly River series (Pale beds) into the

[1]Presented before the Alberta Society of Petroleum Geologists at the Calgary meeting, January 17, 1931. Manuscript received, May 18, 1931. Published by permission of O. B. Hopkins, chief geologist, Imperial Oil, Ltd., Toronto, and A. R. Wilson, manager, production division, Texas Company of Canada, Ltd.

[2]Geologist in charge, Imperial Oil, Ltd.

[3]Geologist, Texas Company of Canada, Ltd.

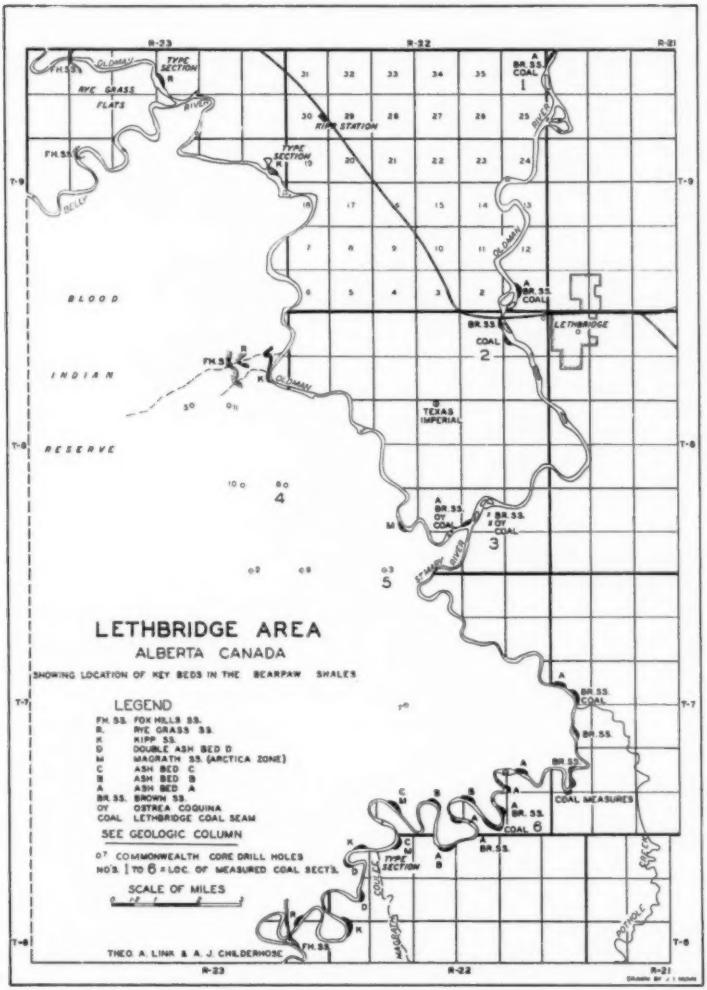

FIG. 1.—Index map of area in vicinity of Lethbridge, showing location of exposures of key beds in Bearpaw shale, and of measured sections and core-drill holes.

overlying dark, navy-blue or steel-gray shales of the Bearpaw beds is well marked by the Lethbridge coal measures which crop out along Old-man and St. Mary rivers west and southwest of Lethbridge. Many measurements of excellent outcrops exposing the entire coal series were made and these were checked with the results obtained in the diamond-core holes. The Lethbridge coal measures, as defined in this paper for the Lethbridge area, consist of one main commercial seam which ranges from 4 to 7 feet in thickness and three other seams of coal ranging in thickness from 6 inches to 2 feet as shown in Figure 2. The *Ostrea* coquina which overlies the highest coal bed is not present everywhere in this area, but its thickness, where observed, ranges from a few inches to 3 feet. The brown-weathering ferruginous sandstone bed, which is considered the top of the Lethbridge coal measures, was found throughout this area and proved to be an excellent datum bed for structural work. It ranges in thickness from 8 inches to 2 feet and its top is regarded as the base of the overlying Bearpaw shale. The interval from it to the upper 2-foot coal bed is notably constant. In fresh drill cores this bed has the same greenish gray appearance as the overlying and underlying sandy shales, but after the cores have been dried and exposed to several months' oxidization, the brownish coloration becomes very noticeable. Other details of the Lethbridge coal measures may be studied in the several sections shown in Figure 2.

At and near the Magrath mine on St. Mary River the Lethbridge coal measures contain more coal seams, none of which is more than 4 feet thick. Due to the presence of the ferruginous brown sandstone member, this splitting of the coal beds does not hamper detailed structure-contour work.

BEARPAW SHALE (726 FEET)

General statement.—According to Dowling,[1] the Bearpaw formation "consists generally of dark shales holding a few ironstone nodules and a few fossils characteristic of the marine part of the Montana group." He ascribed a thickness of 615-622 feet to the Bearpaw shale. The quotation cited, and a faunal list on pages 26-32 of the same memoir, represent nearly all that had been published regarding the Bearpaw shale in the Lethbridge area, prior to the recently issued memoir by Williams and Dyer.[2] Most of the fossils listed in Dowling's memoir were collected in areas many miles distant from Lethbridge.

[1]D. B. Dowling, "The Southern Plains of Alberta," *Geol. Survey of Canada Mem. 93* (1917), p. 25.

[2]M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1931).

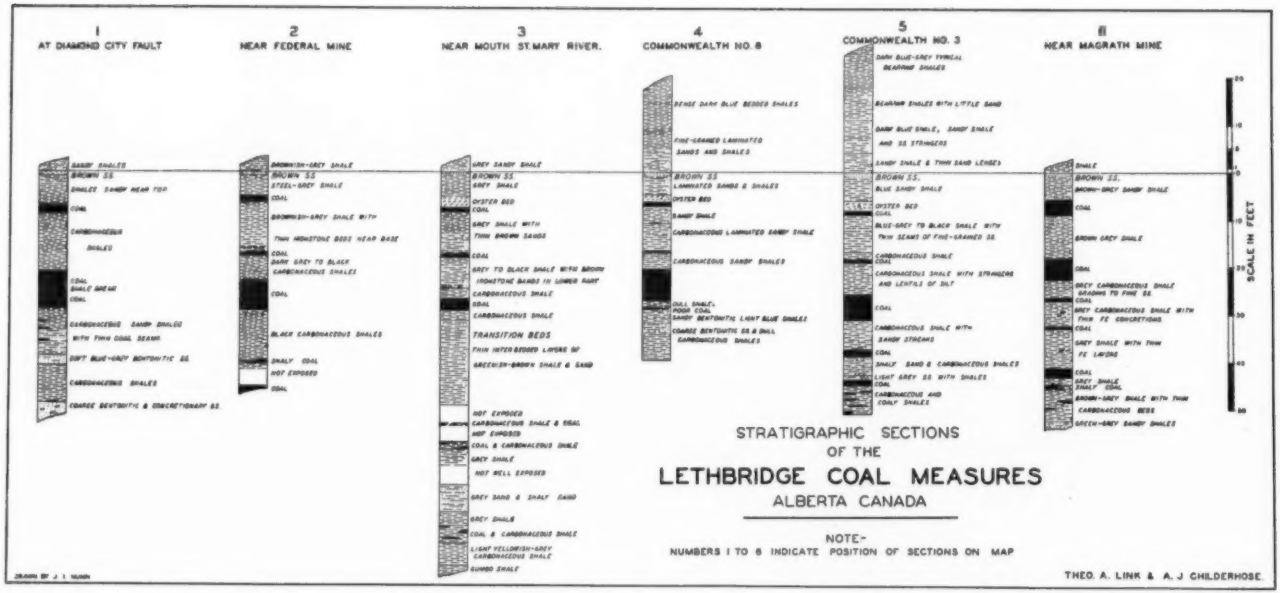

FIG. 2.—Detailed sections of Lethbridge coal measures. Localities are shown in Figure 1.

FIG. 3.—Cut-bank along St. Mary River near Magrath Mine showing ash bed *A*, brown sandstone bed *B*, and coal measures *C*. Minor faulting as shown in this picture is common in Bearpaw shale throughout Lethbridge area. (Photograph by Theodore A. Link.)

Inasmuch as the writers of this paper have found certain definite lithologic units recognizable throughout the entire Lethbridge area, they believe that there is a possibility that some of these may be recognized in other parts of Alberta and Montana. For the present, the names applied to the three sandstone members or zones described in this contribution, are to be regarded as local, and pertaining to this area only.

In broad terms, the Bearpaw shale may be divided into two parts, namely, the lower one-third, which is almost devoid of sands and contains well bedded darker shales, and the upper two-thirds, containing three distinct sandstone members or zones, and lighter bluish or steel-gray, somewhat sandy, shales. There are at least twenty-two distinct bentonite or volcanic ash seams and two distinct fossil zones within the Bearpaw shale. Ironstone and limy concretions are plentiful and many of them contain fossils.

Bentonite beds.—It would be a tedious task to describe in detail the many bentonite beds of the Bearpaw shale. In fact, they all appear alike in the outcrops, except that they range in thickness from ½ inch to 8 inches. Those found bedded within the dark and purer shales are compact, have a soapy or greasy feeling, and a dark greenish or bluish tinge when extracted from the core barrel. After weathering they turn white.

[1]W. H. Twenhofel, *Treatise on Sedimentation* (Williams and Wilkins Company, Baltimore, 1926), p. 205.

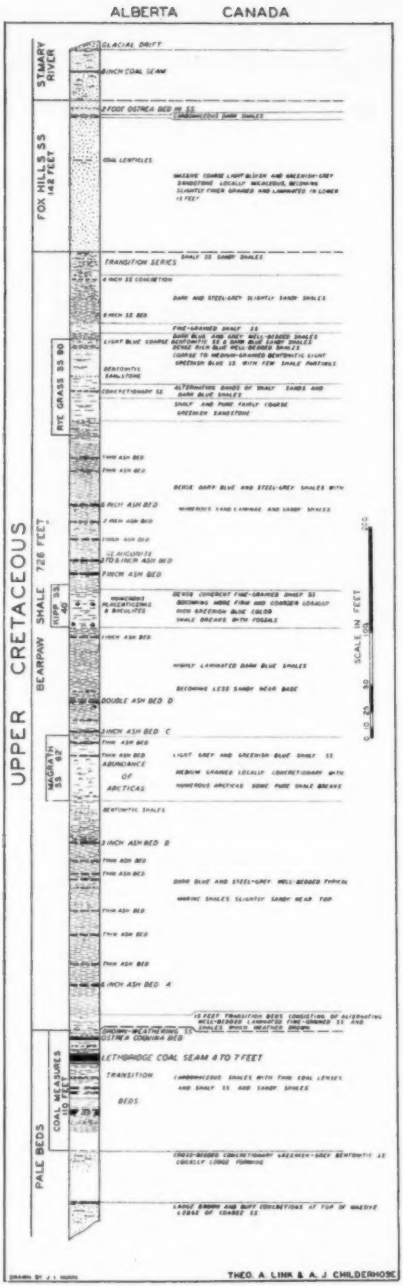
ALBERTA CANADA
UPPER CRETACEOUS
PALE BEDS
COAL MEASURES 10 FEET
PAKOWKI SHALE 726 FEET
FOX HILLS SS 148 FEET
ST MARY RIVER
RYE GRASS SS 80
KOPPS SS 40
MAGRATH SS 92
BEARPAW
GLACIAL DRIFT
8 INCH COAL SEAM
2 FOOT OSTREA BED IN SS
CARBONACEOUS DARK SHALES
COAL LENTICLES
MASSIVE COARSE LIGHT BUFF AND GREENISH-GREY SANDSTONE LOCALLY MICACEOUS, BECOMING SLIGHTLY FINER GRAINED AND LAMINATED IN LOWER 15 FEET
TRANSITION SERIES
SHALY SS SANDY SHALES
6 INCH SS CONCRETION
DARK AND STEEL-GREY SLIGHTLY SANDY SHALES
2 INCH SS BED
FINE-GRAINED SHALY SS
DARK BLUE AND GREY WELL-BEDDED SHALES
LIGHT BLUE COARSE BENTONITIC SS & DARK BLUE SANDY SHALES
DENSE RICH BLUE WELL BEDDED SHALES
COARSE TO MEDIUM-GRAINED BENTONITIC LIGHT GREENISH BLUE SS WITH FEW SHALE PARTINGS
BENTONITIC SANDSTONE
CONCRETIONARY SS
ALTERNATING BANDS OF SHALY SANDS AND DARK BLUE SHALES
SHALY AND PURE FAIRLY COARSE GREENISH SANDSTONE
THIN ASH BED
THIN ASH BED
DENSE DARK BLUE AND STEEL-GREY SHALES WITH
NUMEROUS THIN LAMINAE AND SANDY SHALES
6 INCH ASH BED
2 INCH ASH BED
1 INCH ASH BED
12 INCHES
10 & 1 INCH ASH BED
7 INCH ASH BED
NUMEROUS PLACENTICERAS & BACULITES
DENSE COHERENT FINE-GRAINED SHALY SS BECOMING MORE FIRM AND COARSER LOCALLY
RICH GREENISH BLUE COLOR
SHALE BREAKS WITH FOSSILS
1 INCH ASH BED
HIGHLY LAMINATED DARK BLUE SHALES
BECOMING LESS SANDY NEAR BASE
DOUBLE ASH BED D
3 INCH ASH BED C
THIN ASH BED
THIN ASH BED
LIGHT GREY AND GREENISH BLUE SHALY SS
ABUNDANCE OF ARCTICAS
MEDIUM GRAINED LOCALLY CONCRETIONARY WITH NUMEROUS ARCTICAS SOME PURE SHALE BREAKS
BENTONITIC SHALES
3 INCH ASH BED B
THIN ASH BED
THIN ASH BED
DARK BLUE AND STEEL-GREY WELL-BEDDED TYPICAL MARINE SHALES SLIGHTLY SANDY NEAR TOP
THIN ASH BED
THIN ASH BED
THIN ASH BED
6 INCH ASH BED A
15 FEET TRANSITION BEDS CONSISTING OF ALTERNATING WELL-BEDDED LAMINATED FINE-GRAINED SS AND SHALES WHICH WEATHER BROWN
BROWN-WEATHERING OSTREA CORONINA BED
LETHBRIDGE COAL SEAM 4 TO 7 FEET
TRANSITION BEDS
CARBONACEOUS SHALES WITH THIN COAL LENSES AND SHALY SS AND SANDY SHALES
CROSS-BEDDED CONCRETIONARY GREENISH-GREY BENTONITIC SS LOCALLY LOAD FORMING
LARGE BROWN AND BUFF CONCRETIONS AT TOP OF MASSIVE LEDGE OF COARSE SS
SCALE IN FEET
200
100
50
0
THEO. A. LINK & A. J. CHILDERHOSE

FIG. 4.—Columnar section of Bearpaw shale and contiguous formations near Lethbridge, Alberta.

This is contrary to the statement[1] that: "When pure and unweathered, bentonite has a white to cream color, but in weathering it becomes yellow to brown." The fresh cores all show the bentonite beds to be so nearly the same color as the overlying and underlying strata that some beds might be overlooked on first examination. In churn drill or rotary holes the bentonite fragments, by absorbing water from the drilling fluid, and later drying, appear white. The brown and yellow coloring results from *extensive* weathering. The bentonite beds interbedded with the sandstone or sandy shale members have a lighter blue or greenish tinge. As these generally contain more mica (biotite), they have a less greasy feeling. Because of their impervious nature, considerable amounts of ground water collect on the upper surface of the bentonite beds. This water causes secondary or tertiary alteration of the bentonite. Variously shaped crystals and clusters of selenite are common in the shales overlying and at the top surface of these bentonite beds.

Inasmuch as bentonite is generally recognized as a volcanic ash deposit which accumulated by settling from the surface of the water to the floor of the sea, it is logical to expect exceptional continuity of such beds. An example of a single bentonite bed, having a north-south extent of 445 miles, is reported by Nelson.[1] Many other similar citations are available, but are not included here. It is, however, desirable to refer to Sanderson's[2] unpublished paper in which he reported an extensive distribution of ash beds within the Edmonton, as well as other formations of Alberta. One would expect, therefore, to find the bentonite beds in the Lethbridge area persistent, and correlation of them possible. Before having access to cores from the diamond-bore holes sunk by the Commonwealth Petroleum Company, Limited, the senior writer was successful in using five of the bentonite beds of the Bearpaw shales for structure-contour mapping. The location of some of the outcrops exposing these key beds, is indicated on the accompanying map (Fig. 1). Because of the difficulty in distinguishing one bentonite bed from another, it was necessary to measure the intervals between two, or preferably three such beds. The relationship of one bed with respect to overlying sandy phases or concretionary zones, also furnished sufficient data to establish its identity. An identical method was reported by Rankin[3] in

[1]W. A. Nelson, "Volcanic Ash Bed in the Ordovician of Tennessee, Kentucky, and Alabama," *Bull. Geol. Soc. Amer.*, Vol. 33 (1922), pp. 605-16.

[2]J. O. G. Sanderson, "Upper Cretaceous Ash Beds in Alberta." Read before the 1930 Annual Meeting of the Alberta Society of Petroleum Geologists, Calgary, Alberta.

[3]C. H. Rankin, "Use of Thin Bentonite Beds in Mapping Structure, Rosencrans Area, Kansas and Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 1065-70.

a paper which appeared only a month after completion of the work in the Lethbridge area. This method was also employed with success by the senior writer in the Bearpaw shale of the Manyberries area of Alberta.

The five beds used for such correlation, two of which are only a few inches apart, are indicated by the letters *A* to *D* in Figure 4. Those which were used in conjunction with the lettered beds are merely shown by symbols explained in the stratigraphic column. Many others less than 1 inch in thickness, and not observed in the outcrops, were found in the diamond cores of the test holes sunk in the Blood Indian Reserve.

Because of the nature of these bentonite beds, it is obvious that core "twist-offs" are likely to occur along them. This unfortunate mechanical difficulty must be closely watched by the geologist in charge of such

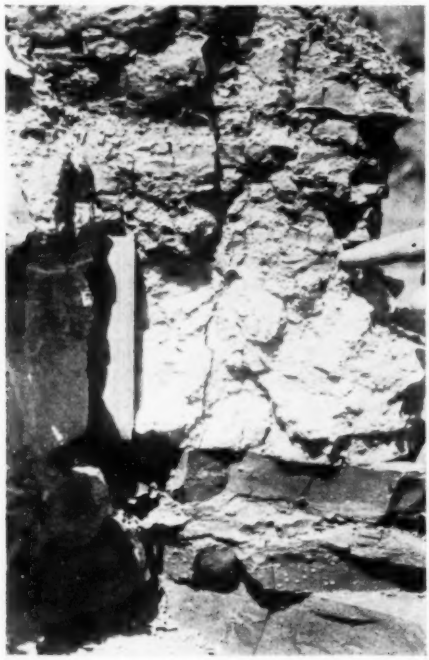

FIG. 5.—Detail of bentonite or ash bed showing sharp contact with overlying and underlying shales. Scale represents 6 inches. (Photograph by Theodore A. Link.)

structure core drilling. As some of the thinner bentonite beds of the Bearpaw shale may have eluded detection from this cause, the number of these beds may be greater than twenty-two, as indicated in the stratigraphic column. Many examples of very bentonitic shale seams, a few

FIG. 6.—Type locality of Magrath sandstone showing lighter color of this member exposed in lower half of cut-bank. (Photograph by Theodore A. Link.)

inches in thickness, were also detected in the cores. The presence of a conspicuous glauconite sand 440 feet above the base of the Bearpaw shale is worthy of note.

Magrath sandstone (*Arctica zone*).—A distinctly sandy zone, consisting of several members having an aggregate thickness of 62 feet, is present in the top part of the lower third of the Bearpaw shale (Fig. 4). The top of this sandy member is 272 feet above the base of these shales. An abnormal profusion of well-preserved *Arctica ovata* fossils characterizes this sandstone.[1] *Arctica* is present in other parts of the Bearpaw shale, but not in such profusion as in this sandstone. Every core hole and all the outcrops show the abnormal profusion of shells in sandstone concre-

[1] M. Y. Williams and W. S. Dyer, *op. cit.*, p. 38, recognize this "*Arctica ovata* zone" on Oldman River, but place it only 170 feet above the base of the Bearpaw shale.

tions which consist almost wholly of these *Arctica* remains. The color of this sandy zone is light greenish, and when observed from a distance it can easily be distinguished from the underlying darker navy-blue and steel-gray shales. Locally it is coarse-grained and its recognition in core holes is easy. The type section of this sandstone may be observed on the south bank of St. Mary River ½ mile downstream from the mouth of Magrath Coulee. As another good section is exposed upstream in this coulee, the name "Magrath sandstone" has been applied to it for local usage. Associated bentonite beds, as shown in Figure 4, are also a great aid in recognizing this *Arctica* sandstone member of the Bearpaw shale.

FIG. 7.—Concretion found in Magrath sandstone, showing profusion of *Arctica* shells. (Photograph by Theodore A. Link.)

A similar sandy zone, containing *Arctica* in profusion and having almost the same stratigraphic position, was recognized by the senior writer in the Manyberries area, 100 miles east of Lethbridge.

Kipp sandstone.—Four hundred and ten feet above the base of the Bearpaw shale is the top of a second distinct sandstone 40 feet in thickness.[1] The double bentonite bed *D* lies between these two sandy zones (Fig. 4). This higher sandstone has been termed the "Kipp sandstone" because of the excellent outcrop found on the north bank of Oldman

[1]M. Y. Williams and W. S. Dyer, *op. cit.*, p. 38, recognize this sandstone and state that the "*Baculites compressus* zone" lies "450 feet below the base." They probably intended to say *above* the base of the Bearpaw shale.

River 1½ miles southwest of Kipp Station. *Placenticeras meeki* (Boehm) fossils are found in profusion above and below this sandstone member. Some of these attain a diameter of 2 feet or more (Figs. 7 and 8). *Baculites* (*B. ovatus*) (Say) are also present in greater numbers than in other parts of the Bearpaw shale. A few *Arctica* were also observed. Both the *Placenticera* and *Baculites* are confined primarily to the shales lying between and above the sandstone members of this sandy zone. Many bentonite beds are found directly above the upper ledge of this sandstone, whereas for some distance below the main sandstone bed very few were observed in the outcrops and the diamond cores, as shown in

FIG. 8.—Kipp sandstone at type locality on north bank of Oldman River. (Photograph by Theodore A. Link.)

Figure 4. Two distinct sandstone members are observable at the high cut-bank outcrop on Oldman River in Sec. 5, T. 8, R. 22, W. of 4th Mer. (Fig. 1). The lighter greenish blue tinge of this sandstone phase makes it easy to distinguish it from the overlying parts of the darker typical Bearpaw shale. The Kipp sandstone is coarse locally, and can readily be distinguished in the diamond cores. Thirty feet above its top a thin zone of glauconitic sand, about 3 feet thick, was observed in the core-holes and at some of the outcrops.

Ryegrass sandstone.—That part of the Bearpaw shale above the Kipp sandstone shows considerable amounts of fine-grained, laminated sand-

stone interbedded with the shale, so that it is difficult to decide whether the beds are shaly sandstone or sandy shale, but the shale does predominate. However, one conspicuous, light greenish blue bentonitic sandstone, with a dark blue 4-foot shale break, emerges 30 feet above the water level on the east bank of Oldman River, just above its junction with Belly River, in the form of a sharp fold. About 30 feet of this sandstone is exposed during low water, but the diamond-drill holes reveal a

FIG. 9.—Large *Placenticeras meeki* found in Kipp sandstone. (Photograph by Theodore A. Link.)

section at least 90 feet of which is dominantly sandstone. This sandstone was seemingly mistaken by Dowling[1] for part of the Fox Hills sandstone. Its top is 642 feet above the base and 84 feet below the top of the Bearpaw shale. Williams and Dyer make no mention of this conspicuous sandstone member, and follow Dowling in ascribing a total thickness of 625 feet to the Bearpaw shale. This sandstone is overlain by typical Bearpaw shale which becomes more sandy as the Fox Hills sandstone is approached. The sandstone is a bright, vivid bluish color, distinguishing it from any other bed in the entire Bearpaw section. It is easily recognized in the diamond cores where encountered below the overlying

[1]D. B. Dowling, *op. cit.*, p. 25.

typical dark blue Bearpaw shale. Because of the proximity of the previously mentioned outcrop to the Ryegrass Flats, the name "Ryegrass sandstone" has been applied to it (Fig. 1). There is no doubt that this sandstone could easily be used as the base of the Fox Hills sandstone or the Edmonton beds in churn drill and rotary cuttings. Locally it is very coarse, cross-bedded, and ripple-marked. Its presence may account for some of the lesser thicknesses ascribed to the Bearpaw shale in near-by areas. It is also very probable that westward from this area practically all of the section below the true Fox Hills sandstone, including the Ryegrass sandstone, might be logged as a part of the former, because of the change to sandy conditions in this part of the section.

FOX HILLS SANDSTONE (142 FEET)

The transition from Bearpaw shale to the overlying Fox Hills sandstone is somewhat abrupt in the Lethbridge area. This is especially noticeable in the diamond-core records in which the contact can be established within an interval of 10 feet. The Fox Hills sandstone has a total thickness of 142 feet. Diamond core-drill records show it to be mainly an unbroken, continuous, massive bed of bright greenish sandstone from the base upward for 126 feet. A 2-foot carbonaceous shale break occurs

FIG. 10.—Fox Hills sandstone as exposed along St. Mary River in Sec. 14, T. 6, R. 23, W. of 4th Mer. (Photograph by Theodore A. Link.)

at this point, which is overlain by 14 feet more of similar massive sandstone containing numerous *Ostrea* fossils. Locally a true coquina is developed (Figs. 4 and 10). Twenty-six feet above the top of the Fox Hills sandstone is an 8-inch seam of highly carbonaceous shale or coal. Between this coal and the Fox Hills sandstone are laminated sandstones and dark blue, hackly shales, typical of the St. Mary River formation. The presence of the marine shells (*Ostrea*) above the first carbonaceous bed in the coarse sandstone identical with that of the main massive part, makes it necessary to include that part in the Fox Hills sandstone.

The weathered Fox Hills sandstone is buff or yellowish brown, and discloses considerable cross-bedding and concretionary phases within the major massive part. These characteristics are not discernible in fresh cores. It weathers into castellated and large mushroom forms similar to the Virgelle sandstone. It is one of the most important horizon markers in southern Alberta.

The diamond-core holes sunk east of the Fox Hills sandstone in the Blood Indian Reserve indicate the existence of a somewhat pronounced cuesta of this sandstone in pre-glacial time similar to the present Virgelle escarpment of northern Montana.

STRATIGRAPHIC HISTORY

The record of sedimentation in the Lethbridge area, as outlined in the foregoing pages, represents one complete cycle or "rhythm" of transgression and regression of the Pierre epicontinental sea. The record, which includes only one of the several advances and retreats of the Cretaceous sea, begins and ends with the deposition of coal and *Ostrea* coquinas.

Coastal lagoon deposits.—The record begins with a sea slowly advancing over the previously deposited fresh-water and possibly sub-aerial sediments of the Pale beds (upper Belly River series). Coastal lagoons and embayments conducive to the accumulation of vegetable matter and brackish-water shells, such as oysters, existed along the shore line of the slowly advancing sea. Although such lagoons and embayments were not, at a specified time, of province-wide extent, they fringed the shore line for many miles. Some of the Lethbridge coal seams, especially the lower seams, may also represent peat accumulations in fresh-water lakes and swamps, which were later inundated by the advancing sea waters. As the shore line advanced, brackish-water lagoons and embayments came into existence along a new belt, again fringing the advanced shore line. In this manner successive coalescing belts of coal and *Ostrea* coquina, and behind them true marine shales, were deposited by

the advancing sea. Therefore, the Lethbridge coal measures represent not one province-wide time period of deposition, but a transgressive sheet, younger on the northwest than on the southeast.

Quiet marine deposition.—This slow advance continued until the entire Lethbridge area was covered by an epicontinental sea in which was deposited the Bearpaw shale. The extremely slow manner in which this was accomplished is attested by the many pure bentonite or volcanic ash beds found in these shales. Obviously there were periods when nothing but volcanic ash was being deposited. At other times marine muds were settling at almost the same rate as the volcanic ash, thus giving rise to the bentonitic shales. The three sandy zones of the Bearpaw shale, and the conditions of the entombed shells, are evidence that

FIG. 11.—Part of large *Placenticeras meeki* Boehm, collected from type locality of Kipp sandstone. Scale in inches. (Photograph by Theodore A. Link.)

these coarser sediments are neither regressive nor transgressive members of the first order. Almost all the bivalve fossils in these sands are intact, indicating no disturbance by wave action or undertow. The Ryegrass sandstone is the first indication that the final stand of the Pierre epicontinental sea was near. Volcanism continued active, as attested by the bentonitic nature of this sandstone. After its deposition, though more shale was deposited, very little advance was made and the sediments record a gradually withdrawing sea. The sediments became sandier and finally the retreating shore line appeared as the Fox Hills sandstone, a true beach deposit containing marine shells found in this environment with a few deeper-sea fossil remains washed up on the beach during periods of severe storms.

Regression.—The regression of the Pierre sea is recorded by the Fox Hills sandstone. The shore-line or beach deposit of sand brought down by rejuvenated streams remains as the Fox Hills sandstone. The *Ostrea* coquina, the carbonaceous shales, and coal seams at the top record a succession of lagoonal deposits accumulated at and near the shore line of the retreating sea. Thus the Fox Hills sandstone represents an overlap sheet which is progressively younger from southern Alberta toward the Gulf of Mexico. The churning action of the waves, littoral currents, and undertow prevented the deposition of bentonite beds within the Fox Hills sandstone. Volcanism undoubtedly continued active, but the work of the waves tended to carry the volcanic ash farther out to sea.

SECTIONS OF BEARPAW SHALE FROM KEHO LAKE TO BASSANO, SOUTHERN ALBERTA[1]

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ABSTRACT

The sections of the Bearpaw shale herewith presented were prepared from a study of cuttings from many shallow test-holes and three deep wells, located within an area extending from T. 11 to T. 21 and from R. 18 to R. 23, W. of 4th Mer., in southern Alberta.

In this area, the base of the Bearpaw shale is limited below by the coal measures at the top of the Pale beds, and at the top by the massive Fox Hills sandstone. The formation is 740 feet thick in the southern part of the area, but this thickness decreases northeastward 230 feet in 65 miles.

The Bearpaw shale consists of three lithologic units. The lower shale member contains bentonite beds, but no sand. The middle sandstone member is generally a fine-grained massive sandstone useful for correlation. The upper sandy member contains sandy shale and erratic sandstone lenses which ordinarily can not be correlated between adjacent wells.

INTRODUCTION

Location.—The localities from which the information contained in this discussion was secured are indicated on the index map (Fig. 1).

With the exception of the Champion district, these localities are situated along a northeast-southwest line, 65 miles in length, approximately parallel with the general strike of the Bearpaw shale. The line of these well sections is on the northwest flank of the Belly River arch. The location of the Champion section is 20 miles northwest of this line, on the eastern edge of the Alberta syncline.

Source of information.—The information used in the preparation of these sections was derived from examinations of cuttings from 139 shallow churn-drill test-holes and from three deep wells drilled as tests for oil and gas. Fifty-two test-holes were located in the Keho district, 5 at Little Bow, 61 at Eyremore, and 21 at Bow River. Deep wells were located at Keho, Champion, and Bassano.

[1]Read before the Alberta Society of Petroleum Geologists at the Calgary meeting, January 17, 1931. Manuscript received, May 18, 1931. Published by permission of the Hudson's Bay Oil and Gas Company, Ltd.

[2]Geologist, Hudson's Bay Oil and Gas Company, Ltd.

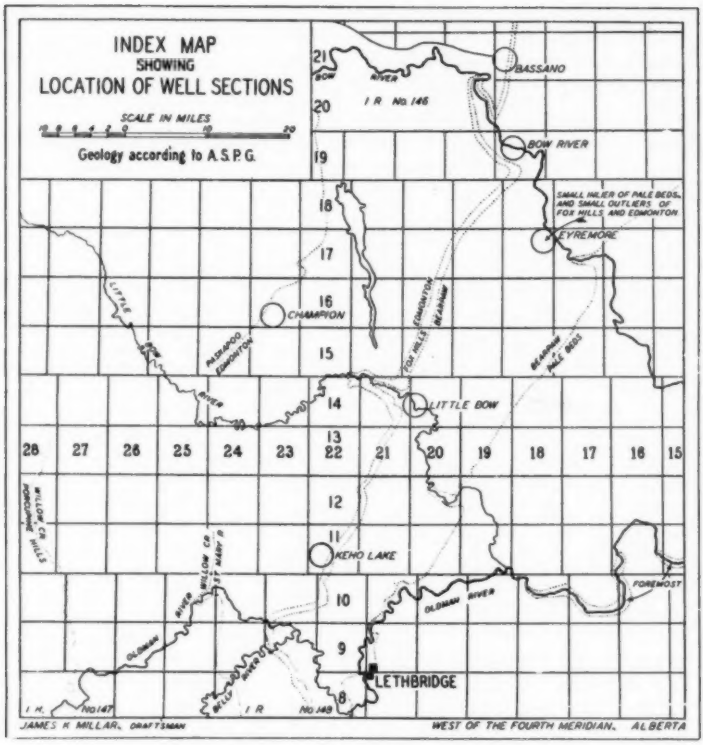

FIG. 1.—Index map of central southern Alberta, showing location of sections illustrated in Figure 2, and outcrop of Bearpaw shale.

Fragments of invertebrate fossils were recognized but could not be used for correlation. In outcrops along Bow River, in the Eyremore and Bow River localities, *Baculites compressus* was especially plentiful in a zone in the upper part of the formation. This probably corresponds with the "*Baculites compressus* zone" of Williams and Dyer.[1] A fairly complete presentation of the paleontology is contained in the recent publication by those authors.

[1]M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1931), p. 38.

STRATIGRAPHY

Relationships of Bearpaw shale.—The Bearpaw shale overlies the Pale beds. This contact is marked by the presence of the coal measures at the top of the latter. The top of the Bearpaw is limited by the massive gray and buff Fox Hills sandstone. A transition zone immediately underlying this sandstone is included in the Bearpaw shale.

Thickness.—The Bearpaw shale ranges in thickness from 740 feet at Keho Lake to 510 feet at Bassano, a decrease of 230 feet in a distance of approximately 65 miles. On Little Bow River the formation has a thickness of 600 feet, at Champion 610 feet, whereas at Eyremore and Bow River the thickness is 575 feet. These thicknesses indicate that there is a fairly uniform thinning of the Bearpaw toward the north.

LITHOLOGIC UNITS

The Bearpaw shale consists of three lithologic units. The writer has termed them, in ascending order, the lower shale member, the middle sandstone member, and the upper sandy member.

Lower shale member.—This member occupies approximately the lower one-third of the Bearpaw. It is distinguishable from the remainder of the formation by its markedly less sandy nature. At no place within the areas described were sandstone beds encountered in this part of the formation. The shale comprising this member is predominantly dark gray, pure, and thin-bedded. Bentonite beds are present in the lower shale member but, because of caving from similar beds above, their exact positions could not be determined.

At Keho Lake the thickness of the lower shale member is 220 feet. In the Little Bow River area this shale has a thickness of 230 feet. At Champion the maximum thickness is 250 feet. At Eyremore and Bow River the shale member is 180 feet thick. The log of a well drilled for gas at Bassano is incomplete and does not define the thickness of the member in that locality.

Middle sandstone member.—This member of the Bearpaw immediately overlies the lower shale member and is an easily recognized unit. The sandstone is light gray or greenish gray in color, ordinarily fine-grained, soft, and massive. In a few places it is fairly well indurated and thin-bedded.

The thickness of the middle sandstone member is not uniform. At Keho Lake the average thickness is 35 feet. At Little Bow River it is 70 feet, whereas at Champion, 20 miles farther down the regional dip, a thickness of only 10 feet was encountered. In the Eyremore dis-

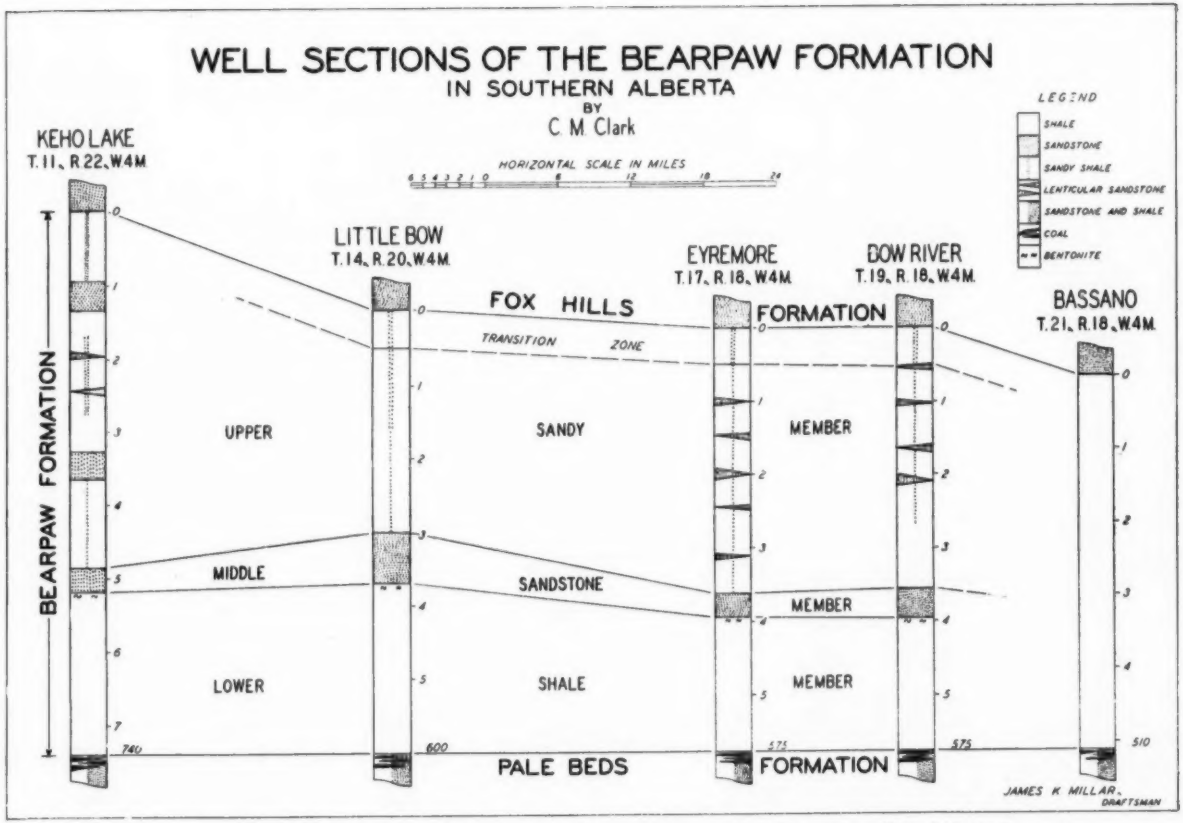

FIG. 2.—Correlation chart showing subdivisions and thickness of Bearpaw shale in area from Keho Lake to Bassano.

trict the member is 35 feet thick, and 12 miles farther north, at Bow River, a thickness of 40 feet was measured. The foregoing figures are the average for each area; the actual thickness penetrated in any individual test-hole may vary as much as 50 per cent.

The middle sandstone member commonly occurs as a single, massive sandstone layer, but in the Eyremore and Bow River districts two other types of occurrence are recognized. One type is that in which the upper half of the member consists of pure sandstone, with the lower half composed of alternating beds of shale and sandstone. A second type occurs in which the positions of the pure sandstone and alternating beds are reversed. The change from one type to another occurs erratically and in many places within short distances.

Almost without exception, a persistent bentonite bed occurs at the base of the middle sandstone member. The color of the bentonite is ordinarily some shade of green, which becomes white on exposure. The interval from the base of the Bearpaw shale upward to this bentonite bed varies from one locality to another, but it is constant within any restricted area. For this reason the sandstone member and bentonite bed proved to be very useful for correlation.

Upper sandy member.—The upper sandy member includes all of the sandy shale and irregular sandstone beds between the middle sandstone member and the upper limit of the Bearpaw shale. This part of the formation is a somewhat lighter gray than that of the lower shale member. Bentonite and concretionary beds are fairly common.

In the Keho Lake area this member is 485 feet in thickness. The lower 120 feet consists of sandy shale, and above this is a gray sandstone bed 40 feet thick. The next overlying unit is 190 feet of sandy shale which logs of some wells show to contain a thin sandstone lens or two. Immediately overlying the shale is another sandstone bed 40 feet in thickness. This sandstone is very similar to others in the upper sandy member, but is in some places distinguished by a thin seam of carbonaceous shale and very lustrous coal at the top. The remaining 95 feet of the member consists of sandy shale.

In the Little Bow River area the upper sandy member consists of 300 feet of sandy shale. Sandy, banded, transition beds occur in the upper 50 feet.

At Champion the upper sandy member is 380 feet thick. A thin bed of gray sandstone occurs 220 feet below the top of this member.

In the Eyremore district the corresponding part of the Bearpaw has a thickness of 360 feet. There are five sandstone lenses, which in color and texture are practically identical, although in some test-holes none was present. As the number and thickness of these lenses at any point is extremely unreliable, they are not suitable for correlation.

On Bow River in T. 19, R. 18, the upper member of the Bearpaw is 355 feet thick. Its character at this locality is similar to that at Eyremore. In one test hole, which penetrated the upper part of the Bearpaw, no sandstone beds were encountered, but in other holes as many as four lenses were present. As at Eyremore, these are lenses of very limited lateral extent and ordinarily can not be correlated even between adjacent holes which are not more than a mile or two apart. The thickness of the lenses ranges from 5 to 30 feet, with an average of 10 feet. In this vicinity, the upper 50 feet of the Bearpaw is represented by distinctly banded transition beds.

HISTORY

The Pale beds underlying the Bearpaw shale consist of alternating sandstones, shales, and sandy shales of continental origin. This unit, together with the Foremost formation, forms a wedge between the marine Pakowki below and the marine Bearpaw above.[1] The change from continental to marine deposition was accomplished gradually, as evidenced by transition beds which occur in places at the base of the Bearpaw. In some beds, however, true marine shale lies in contact with the upper coal bed or carbonaceous seam of the Pale beds.

The Bearpaw shale represents a second advance of the Montana sea; the first transgression is represented by the Pakowki (Claggett) formation. The sediments of the lower shale member were deposited far from shore in calm water. This is indicated by the presence of fine, uniform shale, and bentonite seams.

The middle sandstone member represents a marked partial regression of the Bearpaw sea, sufficient for the deposition of off-shore sands within the area described in this paper. This was followed by a time interval during which fluctuating marine conditions prevailed. A larger amount of sandy material than is present in the lower shale member was deposited with the muds, to produce the sandy shales of the upper sandy

[1] M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1931).

member. The sandstone lentils of this member indicate a nearer-shore phase of deposition with varying currents.

A farther and final retreat of the Montana sea is indicated by the character of the Fox Hills sandstone, a definitely near-shore or littoral type of deposit.

FOX HILLS FORMATION IN SOUTHERN ALBERTA[1]

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ABSTRACT

The Fox Hills formation, originally described by Meek and Hayden in Dakota and Wyoming, can be recognized in southern Alberta as a clearly defined mappable stratigraphic unit. It is a marine sandstone overlying a transition zone in the top of the Bearpaw shales, with brackish-water sediments at the top underlying the lowest St. Mary River coal. Its thickness as observed ranges from 21 to 327 feet. It thickens southward and westward. A distinctive faunal list is given and stratigraphic details at nine localities are described.

INTRODUCTION

The Fox Hills sandstone, although a relatively thin formation, is worthy of discussion for several reasons. It crops out in many localities in southern Alberta. Its lithology compared with contiguous formations is distinctive. It is one of the few essentially marine sandstones of noteworthy thickness in the stratigraphic column of the plains of Alberta. The Fox Hills bears an easily recognizable and characteristic invertebrate fauna which is generally found, at least in part, wherever there are good outcrops. Because of these features, the Fox Hills in southern Alberta is a most useful horizon from which to work in studying the stratigraphy of the plains and outer foothill regions in the south.

The Fox Hills was named by Meek and Hayden[3] in 1861. The type locality is Fox Hills in north-central South Dakota; but the authors mentioned several other localities in Wyoming and Montana where the formation was equally well exposed and showed essentially the same characteristics. The Fox Hills formation has since been found to be widely distributed; in fact it occurs throughout most of the area once occupied by the Upper Pierre sea. Its characteristics, wherever observed,

[1]Presented before the Alberta Society of Petroleum Geologists at the Calgary meeting, January 16, 1931. Manuscript received, May 18, 1931. Published by permission of O. B. Hopkins, chief geologist, Imperial Oil, Ltd., Toronto, Ontario.

[2]Geologist, Imperial Oil, Ltd.

[3]F. B. Meek and F. V. Hayden, "Descriptions of New Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary Fossils, Collected in Nebraska Territory, with Some Remarks on the Rocks from Which They Were Obtained." *Proc. Acad. Nat. Sciences, Philadelphia* (1861), pp. 415-47.

are constant, and in all localities are closely comparable with those of the type region. For the foregoing reasons the writer can see no urgent necessity for giving the formation in Alberta a new name. The term Fox Hills has priority; it has become well known, is understood by the geological fraternity, and is firmly established in the literature. Therefore it should be retained to designate this part of the Upper Cretaceous column wherever it is reasonable and practicable to do so.

DEFINITION OF FOX HILLS FORMATION IN ALBERTA

The Fox Hills is bounded by well defined strata in the southern plains. The thick, dark shales of the Bearpaw lie below it, and the top is marked by *Ostrea* coquina beds and coal seams.

In a general way it may be described as a relatively coarse, massive sandstone of marine origin lying between the Bearpaw shale and the fresh-water strata of the St. Mary River and Edmonton formations.

It is proposed here to define the Fox Hills in Alberta as: *those arenaceous strata, containing a few dark shale beds, lying above the interbedded, thin shale and sandstone transition beds at the top of the Bearpaw, and below the top of the highest brackish-water fossil horizon in this unit group, and immediately above which is the basal coal seam of the fresh-water St. Mary River series.*

This definition is applicable to those sections where the Fox Hills is best developed, but in other regions the bounding strata are of quite different character. However, in most places where this is the fact the Fox Hills proper has also lost its identity.

GENERAL CHARACTERISTICS, ORIGIN, AND DISTRIBUTION IN ALBERTA

In outcrops the main body of the Fox Hills is pale buff sandstone. Its unweathered color is greenish gray. The sand is ordinarily of relatively coarse texture, with a small clay content, and generally has a calcareous matrix. The essential component mineral is quartz, in contrast to the feldspathic character of the St. Mary River formation and Pale beds. The thick sandstone tends to massive rather than cross-bedded structure, although strongly cross-bedded phases occur in places. A remarkable feature of the formation in Alberta is the uniformity of grain size and degree of rounding of the particles. There is little ironstone in the Fox Hills, and that which occurs is of lean type and in small nodules.

In some places, dark shale in thin beds, commonly holding marine shells, interrupts the normal sandstone section. The character and the manner in which the shale breaks occur indicate the marine origin of this

formation. The sedimentation and fauna at the top of the Fox Hills likewise clearly indicate the paleogeographic conditions at the close of this stage. The upper part of the Fox Hills holds increasing amounts of carbonaceous detritus toward the top. This constitutes good evidence of the seaward advance of continental deposition. The top bed of the Fox Hills is an estuarine phase most prominently characterized by thick beds of *Ostrea*. In places these are preceded by a thin coal bed, but most commonly are succeeded by a thick coal seam. This seam is usually regarded as the basal bed of the continental St. Mary River formation.

In origin, the Fox Hills is closely related to the Upper Pierre or Bearpaw. The faunas and geographical distribution of the two formations demonstrate this fact. In many respects the faunas are identical except that the more fragile types like *Placenticeras meeki* are rarely found preserved in the sands.

Ordinarily the distinctly marine Bearpaw shales pass conformably and directly through a thin transition zone into coarse sandstone above. There is a thin zone of alternating thin beds of brown sand and dark brown to dark gray shale, which is of distinct Bearpaw type; this constitutes the transition phase.

This sudden change in coarseness of the detritus which was deposited in the Pierre sea indicates a marked change of conditions at the source of the sediments. There was either a pronounced positive diastrophic movement in that region, or a radical variation in climate. It is probable that a combination of these influences was effective. The positive diastrophic movement was probably preliminary orogenic adjustment related to the second Laramide revolution. There is also evidence that there was some elevation of the entire northern interior region at this time; not enough, however, to cause the immediate recession of the Pierre sea. Arenaceous deposits reached this basin and were distributed entirely across it at this time. This deposition may have attained almost perfect adjustment to "base level of deposition," as postulated by Barrell. If it is assumed that this stage of sedimentation was attained in Fox Hills time, a sufficient explanation of the great areal distribution of this thin, uniform formation is provided.

It seems evident that most of the sediments of the Fox Hills originated along the rising eastern flank of the Cordillera, for the formation thickens westward. There may also have been some contribution from minor uplifts which had their inception about this time within the central interior region of the continent.

The Fox Hills was not deposited rapidly; cross-bedding is not a predominant feature, and there was relatively complete sorting of its sediments.

In summary, the Fox Hills is an arenaceous formation of littoral marine type. The inception of continental conditions of deposition is recorded in the upper part of the formation, where true marine gave place to estuarine deposits. The source of the sediment was dominantly the western uplands. The area of deposition occupied the northwestern and central parts of the Upper Pierre sea.

In Alberta the Fox Hills is best developed in that region lying south of Bow River. On Red Deer River it has lost its identity as a separate formation. It is exposed in many localities south and west of Lethbridge, and at two points north of there on Little Bow and Bow rivers. The Fox Hills is well developed in the outer foothills belt south and west of Lethbridge and where measured in this belt near the International Boundary, it is much thicker than on the plains. This formation is also exposed on the flanks of the Cypress Hills.

All these areas of Fox Hills exposures are shown on the accompanying sketch map (Fig. 1), the numbers on which correspond with the numbers of the stratigraphic sections which are discussed.

FAUNA OF FOX HILLS FORMATION

In this paper the stratigraphic equivalence of the Fox Hills with formations of related age in the western states is not discussed in detail. For present purposes it is assumed that this formation in Alberta is the equivalent of the Fox Hills of southeastern Montana and northwestern South Dakota. In support of this assumption, the full list of fauna of the Alberta Fox Hills, known to the writer, is here listed. It is believed that a sufficient percentage of this fauna is common to the Fox Hills at these widely separated localities to justify the assumption of their equivalence.

FAUNA OF ALBERTA FOX HILLS FORMATION

BRYOZOA

CHEILOSTOMATA

*Conopeum bicystosum**

CEPHALOPODA

Scaphites ventricosus

PELECYPODA

PRIONODESMACEA

Nucula cancellata
Yoldia evansi
Cucullaea nebraskensis
Inoceramus barabina crippsi
Pteria fibrosa
*Exogyra incipiens**
*Ostrea glabra ponderosa**
Ostrea subtrigonalis
Ostrea glabra
*Ostrea glabra coalvillensis**
Anomia subtrigonalis

TELEODESMACEA

Arctica ovata lata
Corbicula occidentalis
Protocardia subquadrata
Callista cf. *owenana*
Callista deweyi
Mactra (?) *warrenana*
Corbula perangulata

GASTROPODA

CTENOBRANCHIATA

Lunatia sp.
Vivipara conradi
Campeloma producta
Melania whiteavesi
Anchura americana

OPISTHOBRANCHIA

Thaumnastus limnaeiformis

VERMES

Tracks of large and small worms

PISCES

TELIOSTII

Scales sp. undet.

PLANTS

Halymenites major

*Forms recently described by the writer.

DETAILED DESCRIPTION OF FOX HILLS AT SELECTED LOCALITIES

In Figure 2 are shown nine graphic sections of the Fox Hills which have been carefully measured and observed. These are numbered to correspond with locality numbers shown on the map (Fig. 1).

The first locality chosen is that at Del Bonita. The formation is well exposed here in the valley of Milk River, and displays most of the essential features of the Fox Hills which have been mentioned in the foregoing remarks. At the point measured the formation is 121 feet thick. It is to be noted here that the upper phase of the formation is without coal and is a relatively uniform section of pale buff, massive and cross-bedded sandstone. The graphic section depicts the essential features.

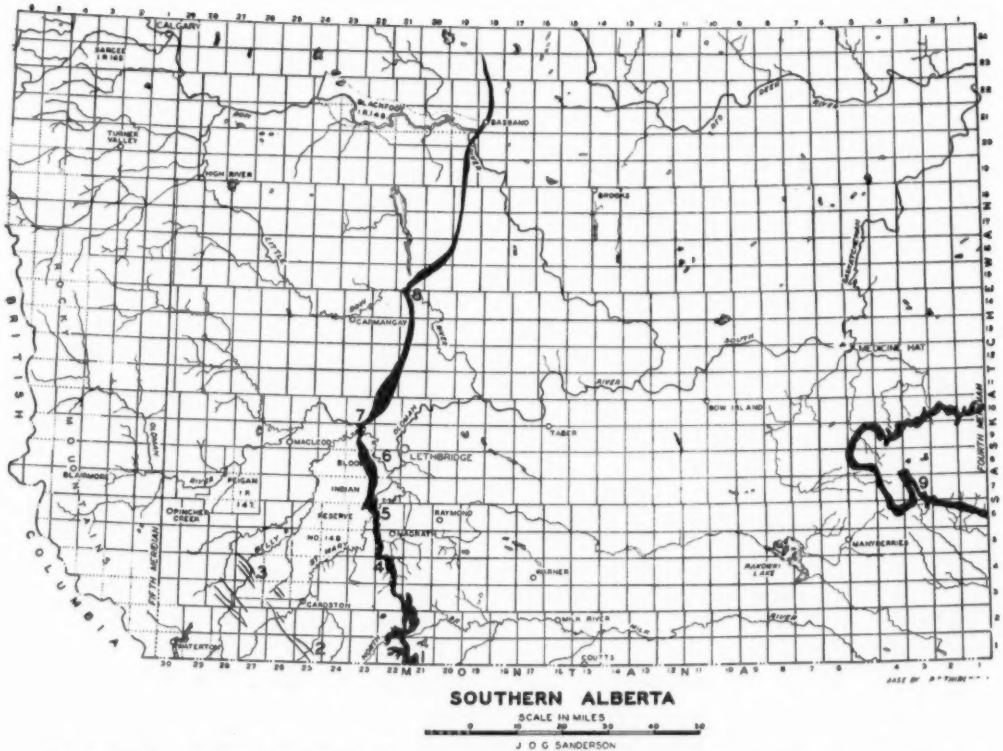

FIG. 1.—Map of southern Alberta, showing location of exposures of Fox Hills formation in black. Numbers 1-9 show locations of correspondingly numbered sections in Figure 2.

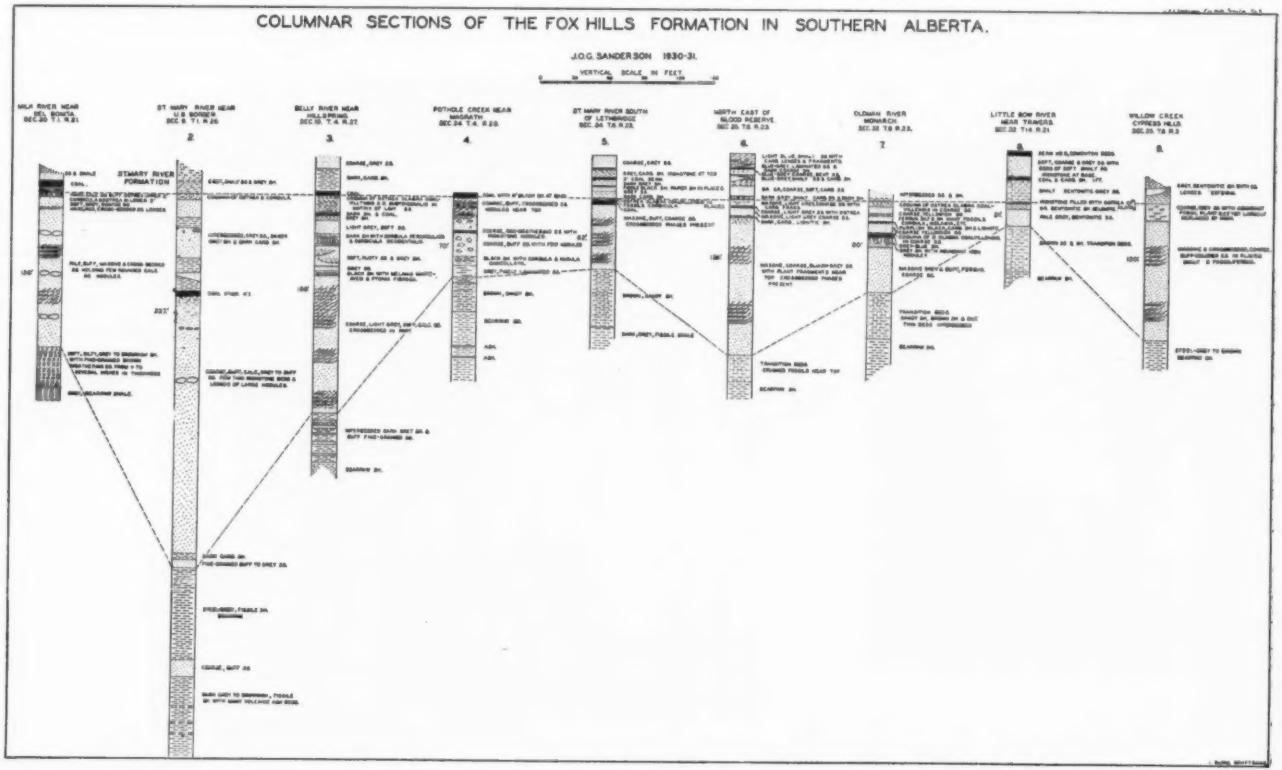
COLUMNAR SECTIONS OF THE FOX HILLS FORMATION IN SOUTHERN ALBERTA.
J.O.G. SANDERSON 1930-31.
VERTICAL SCALE IN FEET.
MILK RIVER NEAR INT. BOUNDARY
ST MARY RIVER NEAR U.S. BORDER
BELLY RIVER NEAR WILLOW SPRING
POTHOLE CREEK NEAR MACGRATH
ST MARY RIVER SOUTH OF LETHBRIDGE
NORTH EAST OF BLOOD RESERVE
OLDMAN RIVER MONARCH
LITTLE BOW RIVER NEAR TRAVERS
WILLOW CREEK CYPRESS HILLS
STIMARY RIVER FORMATION

FIG. 2.—Detailed stratigraphic sections of Fox Hills formation.

FIG. 3.—Fox Hills sandstone exposed along St. Mary River in Sec. 24, T. 6, R. 23, W. of 4th Mer. (Photograph by Theodore A. Link.)

FIG. 4.—Detail of Fox Hills sandstone illustrating wind erosion on massive part. (Photograph by Theodore A. Link.)

The next locality is on St. Mary River about one mile north of the International Boundary. At this place the formation has thickened to 327 feet; the main sandstone bed is 225 feet thick and the interval at this point, between the coal and fossil beds, is thicker. The coal here is developed below the *Ostrea* beds rather than above them, as it is in most places. The sandy transition phase commonly found below the Fox Hills is lacking.

The place where the Fox Hills is most completely developed in Alberta, is at locality 3 on the map. This outcrop is found in the canyon of Belly River near Hillspring, west of Cardston. Here there are three well developed fossil horizons above the main sandstone body. The lowest of these contains the most typically marine fauna and the highest, the least typically marine fauna. In contrast to the St. Mary River section, the main coal development here is above the *Ostrea* horizon rather than below. Only a thin bed of coal occurs below the *Ostrea* zone in this vicinity. An interesting feature here is the thickness of the *Ostrea glabra coalvillensis* bed. Between Belly River and Cardston the same bed is nearly 30 feet thick and includes a thin coal seam.

Locality 4 on the map is an outcrop on Pothole Creek, just south of Magrath. The Fox Hills protrudes here and locally forms steep canyon walls where cut by the stream. The formation is only 80 feet thick; the *Ostrea* beds commonly present at the top are locally absent and cross-bedding is well developed in the upper part. A short distance above the base an 8-foot shale contains a meager but unique fauna, including

FIG. 5.—Fox Hills sandstone west of Cardston, Alberta, Sec. 10, T. 3, R. 26, W. of 4th Mer. Notice castellated forms and cross-bedding. (Photograph by P. D. Moore.)

FIG. 6.—Thick *Ostrea* coquina near top of Fox Hills sandstone. Outcrop in Blood Indian Reserve, Sec. 31, T. 3, R. 26, W. of 4th Mer. Man at left stands at base and man at right on top of bed. (Photograph by P. D. Moore.)

Nucula cancellata and a giant variety of *Corbicula*. The ordinary transition phase is present at the top of the Bearpaw.

Locality 5 is the point where the St. Mary River cuts diagonally across the strike of the outcropping Fox Hills. The entire formation here is 62 feet thick, and is mostly sandstone. A thin coal seam is present with both *Corbicula* and *Ostrea* horizons above the coal. The main basal St. Mary River seam occurs above the fossil horizons.

One of the most complete records of the Fox Hills is that obtained by core-drilling on the Blood Indian Reserve. The section shown is taken from bore hole No. 11 drilled by the Commonwealth Petroleum, Limited, in Section 25. The upper bed of the formation contains a 2-foot lithified coquina of *Ostrea*. The sandstone for 5 feet above the *Ostrea* bed closely resembles that of the Fox Hills and may properly be included as such. This section is composed of little else than coarse bluish gray sandstone to the base. The formation here is 142 feet thick.

A relatively short distance away, at Monarch (locality 7 on the map), the thickness and general characteristics of the Fox Hills are materially changed. The transition series below is thicker and the Fox

Hills sandstone thinner than ordinary. The upper part of the formation includes three fossil beds: two *Ostrea* beds with a dark shale containing plentiful *Melania* between the two. There are two thin lignitic shale beds below the upper *Ostrea* stratum.

Perhaps the most significant exposure of the Fox Hills is that shown in section 8 which was measured on Little Bow River in Sec. 32, T. 14, R. 21. The Fox Hills here has thinned to 21 feet. The typical coarse, buff-weathering sandstone is only 15 feet thick. The *Ostrea* bed is confined to a thin ironstone stratum which is directly above a 5-foot bed of very selenitic shale. In this district the sands and shales above show the general features of the Edmonton rather than those of the St. Mary River formation. Farther north on Bow River there is only a trace of Fox Hills present, and the same condition exists on Red Deer River. At these localities the transition series becomes more sandy, *Ostrea* beds occur within it, and the Edmonton section is in direct contact with the transition phase at the top of the Bearpaw shale.

The last section shown, No. 9, is one measured on Willow Creek on the south flank of Cypress Hills. There is no coal at the top of the section here, but the upper 15 feet of the formation contains much partly carbonized fossil wood and thin stringers of fossil peat. The typically Fox Hills part of the section is 105 feet thick. The oyster beds are locally absent, but occur in other parts of this region. There are also beds of *Ostrea subtrigonalis* immediately beneath the Fox Hills in Medicine Lodge Coulee.

Diverse statements regarding the Fox Hills in this vicinity have been made by W. S. Dyer and M. Y. Williams of the Geological Survey of Canada. Dyer[1] concludes that the Fox Hills is 150 feet thick, is composed of gray sand and brown cross-bedded sandstone weathering in ledges, and is overlain by Lance beds. Williams,[2] however, has placed the thickness at 230 feet[3] in the same locality. He describes it as yellow-weathering silts and sands with marine shell beds and believes it is overlain by Fort Union beds. From these statements it may be deduced that there is some confusion as to the upper boundary of the Fox Hills forma-

[1] *Geol. Survey of Canada Summary Rept., 1926*, Pt. B (1927), p. 16 b.

[2] *Trans. Royal. Soc. of Canada*, Sec. 4 (1928).

[3] M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930), p. 41.
In this report these writers place the Fox Hills thickness at 370 feet, which gives them credit for statements of three different thicknesses for the Fox Hills at this locality.

tion in the Cypress Hills country. There is reasonably convincing evidence that the so-called Esteven and Whitemud formations of the Cypress Hills area represent the middle Edmonton and upper part of the basal Edmonton section as developed on Red Deer River. It is most probable that the beds above the typical Fox Hills, the thickness of which was previously stated, represent the lower part of the Edmonton.

It should be noted that there seems to be considerable local variation in the Fox Hills in this region. The coarse sandstone is replaced by silty fossiliferous beds at some places in Medicine Lodge Coulee.

CONCLUSION

The Fox Hills is a distinct lithological unit in southern Alberta and has all the characteristics required to class it as a formation. It has a wide geographical distribution and crops out through a large area.

The formation is essentially of marine origin, but its different character at the top anticipates the continental deposition which succeeded it. It is evident that the thickness varies considerably, although the lithologic characteristics and fauna are pronouncedly constant. The formation thickens moderately toward the south, and markedly toward the west. The formation thins and disappears toward the north before the central part of the province is reached. It is replaced by the overlying and underlying formations in this direction. Its similarity to the typical Fox Hills both faunally and lithologically is deemed sufficient reason for retaining this formation name in Alberta.

DISCUSSION

J. S. IRWIN, Calgary, Alberta: I wish to confirm the observations and conclusions of Dr. Sanderson concerning the Fox Hills sandstone and to emphasize the importance of this formation as a widespread horizon marker. The Fox Hills sandstone is remarkably uniform in character and appearance from the Denver basin in Colorado northward through Wyoming, Montana, and southern Alberta and eastward into the Dakotas and Saskatchewan. It is also extremely probable that the *Halymenites*-bearing Trinidad sandstone of southern Colorado and northern New Mexico is an equivalent formation. In its remarkable lateral extent the Fox Hills is similar to the Dakota sandstone, but is more similar in its lithology and mode of deposition to the Eagle (Milk River) sandstone.

As pointed out by Dr. Sanderson, the Fox Hills possesses a fairly rich and distinctive marine fauna, but he failed to emphasize what to my mind is the most distinctive fossil, namely, the fossil sea-weed, *Halymenites major*. It is known, of course, that *Halymenites* occurs both above and below the Fox Hills sandstone, but the very profusion and universal occurrence of this fossil plant in the Fox Hills, in contrast to its comparative scarcity, at least in older strata, seems to justify its consideration as diagnostic. *Halymenites* has been

observed in practically every outcrop of Fox Hills sandstone seen by the writer and it is reported in that sandstone throughout the area of its outcrop in New Mexico, Colorado, Wyoming, Montana, and the Dakotas. So similar are many of the Fox Hills outcrops in the area south of Lethbridge, Alberta, to the Milliken member of the Fox Hills north of Denver, Colorado, in the matter of lithologic character and *Halymenites* content that they could not be differentiated. The *Halymenites*-bearing sandstone of the Fox Hills formation was, in fact, formerly called the "*Halymenites* sandstone" in the Denver basin.

STRATIGRAPHY OF SPRING COULEE WELL[1]

W. S. YARWOOD[2]
Calgary, Alberta

ABSTRACT

The Spring Coulee well is located 40 miles south and west of Lethbridge, Alberta. The glacial drift here is underlain by the St. Mary River formation, Subsurface formations penetrated by the well are the marine Foxhills sandstone, the marine Bearpaw shale, the Belly River group, the marine Colorado shale, the Blairmore formation, the marine Fernie shale, and the upper Paleozoic limestone. The stratigraphy of these formations is described and correlations are suggested.

ACKNOWLEDGMENTS

The writer takes pleasure in expressing his appreciation to W. P. Mellen and F. W. Rohwer for their collaboration and suggestions, and to many members of the Alberta Society of Petroleum Geologists. P. D. Moore furnished information on the stratigraphic correlation between Spring Coulee and Turner Valley, and J. O. G. Sanderson made tentative identifications of the fossils in the Bearpaw and Belly River group. P. S. Warren has examined and reported on fossils from various parts of the section.

LOCATION

The Spring Coulee well commenced drilling on April 11, 1930, in Sec. 15, T. 4, R. 23, W. of 4th Mer. The well is about 3½ miles south and east of the village of Spring Coulee, Alberta.

EXPOSURES

The rocks encountered in the upper 1,200 feet of the well, and higher beds, are exposed along St. Mary River. West of the well and northeast of the town of Cardston, rocks of Tertiary and Upper Cretaceous age are exposed. The Willow Creek formation, of doubtful Eocene age, may be observed along the river between Cardston and Raley. These sediments, which consist of alternating beds of sand, clay, and sandy

[1]Read before the Alberta Society of Petroleum Geologists, January 16, 1931. Manuscript received, May 18, 1931. Published by permission of Alberta Pacific Consolidated Oils, Ltd., Calgary, Alberta.

[2]Geologist, Alberta Pacific Consolidated Oils, Ltd.

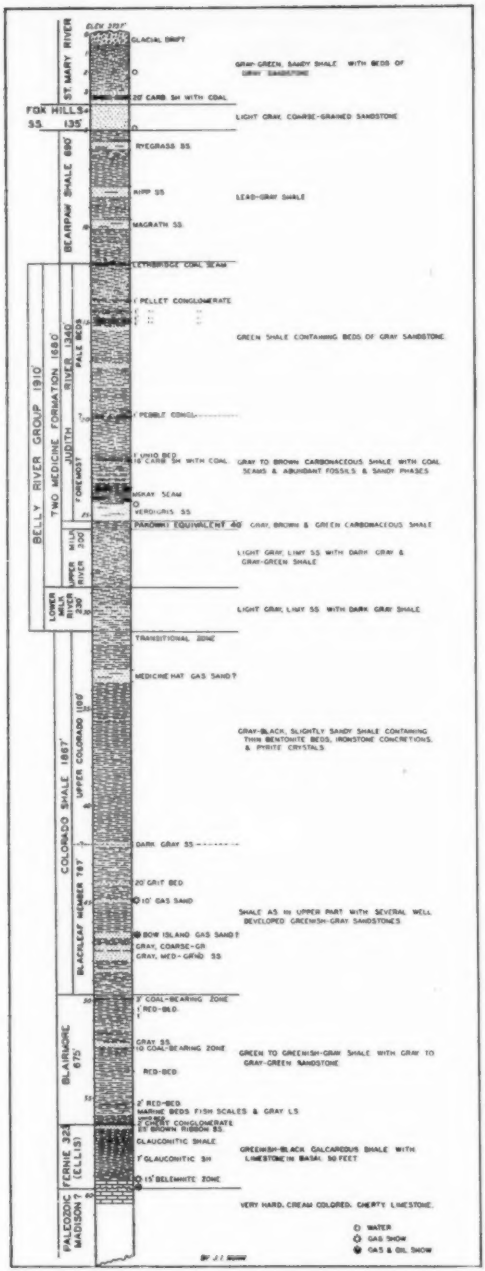

FIG. 1.—Abridged log of Spring Coulee No. 1, Alberta. Depth, 6,000 feet plus.

clay, have a characteristic reddish tint. Below the Willow Creek beds, a thick succession of gray sandstones and light green shales are included under the name of St. Mary River formation, the youngest Cretaceous rocks in this vicinity. A good section of the lower part of this series of rocks extends along the river from the vicinity of Spring Coulee to a place near the northeast corner of T. 6, R. 23, W. of 4th Mer. The Spring Coulee well penetrated the lower 305 feet of this formation. The section lies conformably on the Fox Hills sandstone at the place previously mentioned. The Fox Hills formation has a thickness of about 135 feet and consists entirely of medium-grained, light gray sandstone. The outcrop of this sandstone is somewhat narrow and decreases in width toward the north. It is in contact with the Bearpaw shale in the locality mentioned previously, and northeastward from that place the Bearpaw shale is exposed along St. Mary River as far as its confluence with Oldman River. An outcrop on the river, where Pothole Creek flows into it, shows the contact of the Bearpaw shale and the underlying Pale beds. The region immediately east of Lethbridge is underlain entirely by the Belly River group and nowhere do rocks of Colorado age crop out.

DETAILED DESCRIPTION AND AGE DETERMINATION OF ROCK SAMPLES RECOVERED

The well is being drilled with rotary tools. It was cored at the following depths: 1,130-1,150; 1,640-1,670; 1,750-2,440; 4,650-5,970 feet. Where not cored, the determinations were made from rotary cuttings.

The sections given under formations are somewhat condensed from the complete log.

ST. MARY RIVER FORMATION

The basal 305 feet of this formation, as penetrated, consists of gray-green sandy shales, and beds of gray sandstone. One of these serves as a source of water supply for local residents. The top of the section contains traces of gypsum and at 30 feet above the base there is a 10-foot zone of black, carbonaceous shale.

ST. MARY RIVER SECTION

Depth in Feet	*Description*
60	Top of section
80	Green shale with trace of gypsum
190	Dark gray shale with less green shale and gray sandstone
300	Green shale with less dark brown to gray and a few gray sandstone beds
320	Gray sandstone with a little coal
340	Carbonaceous shale containing coal
365	Gray-black shale with fragments of gray sandstone

FIG. 2.—Typical exposure of St. Mary River formation, showing evenly bedded nature of alternating sandstones, calcareous nodules, and shales. On north bank of St. Mary River, Sec. 9, T. 5, R. 23, W. of 4th Mer. (Photograph by P. D. Moore.)

FOX HILLS FORMATION

The change from St. Mary River beds to Fox Hills sandstone is pronounced and can be readily recognized. The characteristic overlying light green shales of the former are not present in the latter formation; in fact, scarcely a trace of argillaceous material can be seen. The sand grains are coarse, light gray, and associated with them are grains of a black ferro-magnesian mineral. The formation has a thickness of 135 feet and the lower 20 feet contains water.

FOX HILLS SECTION

Depth in Feet	*Description*
365	Top of section
380	Gray, micaceous sandstone
480	Gray sandstone with a few coal fragments
500	Gray sandstone containing water

BEARPAW SHALE

In contrast to the Fox Hills sandstone this formation is predominantly lead-gray shale, in which occur three sandy members. The formation has a thickness of 690 feet.

BEARPAW SHALE SECTION

Depth in Feet	*Description*
500	Top of section
550	Lead-gray shale
560	Shale containing bentonite
600	"Ryegrass" sandstone. 65 per cent dark gray sandstone and 35 per cent lead-gray shale
640	Lead-gray shale with minor dark gray sandstone
650	Lead-gray shale with ironstone
750	Lead-gray shale
760	Lead-gray shale with shell fragments and coal
790	Lead-gray shale
850	"Kipp" sandy member. 50 per cent dark gray sandstone and 50 per cent lead-gray to dark brown shale
900	Lead-gray shale with sandstone fragments
910	Lead-gray shale with ironstone
936	Lead-gray shale containing *Nucula* probably
960	Lead-gray shale containing bentonite
1,010	"Magrath" sandy member containing bentonite
1,030	Lead-gray shale
1,070	Lead-gray shale containing bentonite and ironstone
1,090	Lead-gray shale containing *Dentalium gracile*
1,100	Lead-gray shale containing ironstone and bentonite
1,150	Lead-gray shale
1,190	Lead-gray shale with *Placenticeras meeki*, *Inoceramus*, *Ostracoda*, *Corbula perangulata*

The upper part of the section is lacking in detail because no cores were taken, but below 1,100 feet from the surface cores were cut. Several fossils were obtained from cores, ostracods being regarded as the most interesting. These are found in small joints which cut across the bedding planes at steep angles. The fossils are chitinous and are microscopic in dimensions. This is probably the first locality in which they have been reported. Associated with them are plants apparently of a marine flora. These may represent a part of the shore-line life which flourished when the sea, in which the shales were deposited, transgressed upon the fresh-water deposits of Pale beds age. *Placenticeri* occur in ironstone concretions and some large forms of these were evidently more than a foot in diameter. The nacreous shells are well preserved and on one a bryozoan was observed.

BELLY RIVER GROUP

The term Belly River group, as used here, includes the Pale beds, and the Foremost, Pakowki, and Milk River formations. The Two Medicine formation of Montana, west of the Sweetgrass arch, includes all of the Belly River group except the Lower Milk River, or Virgelle sandstone. The term Belly River, as used by the Canadian Geological Sur-

vey, is restricted to the Pale beds and the Foremost formation,[1] and is equivalent to the formational name Judith River, of Montana.

The Pale beds and the Foremost formation are not markedly different, either lithologically or paleontologically, and the contact between them is not well defined.

Pale beds.—These beds consist primarily of green shale, and not more than 20 per cent of the entire section consists of gray sandstone. Fossils are rare and scattered. At the top of the formation several occur associated with carbonaceous shale (Lethbridge coal seam).

PALE BEDS SECTION

Depth in Feet	*Description*
1,190	Top of section
1,200	Gray sandstone with coal and brown carbonaceous shale. *Viviparus conradi ?, Unio danae* and *Anodonta ?* sp.
1,265	Lead-gray and gray-green shale containing coal in upper part
1,382	Gray-green shale with beds of gray sandstone. *Viviparus?* sp., *Sphaerium?* sp. (1,337 feet), fish scale (1,356 feet)
1,383	Pellet conglomerate. *Campeloma multilineata ?, Valetella pabtista ?*
1,441	Gray-green shale with thin sandstone beds containing plant remains. *Campeloma multilineata* (1,400 feet)
1,442	Pellet conglomerate
1,477	Pale green shale with thin, gray sandstone beds
1,478	Pellet conglomerate
1,485	Pale green shale
1,492	Gray, micaceous sandstone
1,495	Pale green shale
1,496	Pellet conglomerate and gray sandstone
1,500	Pale green sandstone
1,518	Olive-green shale. *Goniodiscus ?* sp. (1,516 feet)
1,538	Gray sandstone
1,710	Gray-green shale. *Campeloma* sp. (1,638 feet). *Sphaerium* cf. *formosum Campeloma* cf. *limnaeiformis. Campeloma* sp. (1,678 feet)
1,730	Gray sandstone
1,820	Gray-green shale
1,830	Gray sandstone
1,960	Gray-green shale containing *Physa copei* at 1,954 feet
1,980	Greenish brown shale
1,981	Greenish brown shale containing pebbles
2,134	Gray-green shale. *Sphaerium* cf. *formosum* (1,983 feet)
2,145	Blue-gray, conglomeratic sandstone
2,170	Gray to green shale. *Viviparus reynoldsanus, Physa copei* (2,160 feet)

At least four 1-foot beds of pellet conglomerate occur in this section. The pellets are of subangular, green shale with reptilian bones in places, and the matrix consists of gray sandstone.

Foremost.—The section assigned to the Foremost does not differ greatly from that of the Pale beds, but on the whole the rocks are more

[1] M. Y. Williams and W. S. Dyer, "Geology of Southern Alberta and Southwestern Saskatchewan," *Geol. Survey of Canada Mem. 163* (1930), p. 11.

carbonaceous and contain more coal seams. Fossils, particularly *Unio*, are plentiful in certain beds. A noteworthy feature is a lack of induration and a marked tendency on the part of the shales to shear and slickenside.

FOREMOST SECTION

Depth in Feet	*Description*	
2,170	Top of section	
2,188	Dark brown to gray-green shale containing beds of gray sandstone; *Sphaerium* sp. *Campeloma* sp.	
2,189	*Unio* bed containing *Unio danae* and *Unio mclearni*	
2,205	Dark gray to brown shale containing coal and a little amber; *Martesia* sp.?, *Sphaerium* sp.?, and *Viviparus* cf. *conradi*	
2,214	Dark brown to gray-green shale. *Campeloma* sp.; *Physa ?* sp. and *Sphaerium formosum*	
2,219	Gray, micaceous sandstone	
2,231	Dark gray to green shale characterized by large specimens of *Unio* sp.?	
2,275	Dark gray to green shale	
2,280	Gray sandstone	
2,299	Dark brown to gray-green shale	
2,312	Gray sandstone, fine-grained, hard	
2,321	Gray-green, soft, friable shale	
2,330	Gray sandstone containing petrified wood	
2,352	Dark gray shale	
2,373	Dark brown and gray-green shales with coal. *Unio* sp.? and *Viviparus reynoldsanus*	
2,392	Dark gray shales and thin beds of gray sandstone	
2,394	Bentonite	
2,414	Dark brown carbonaceous shales containing thin beds of coal	McKay coal
2,415	Coal	
2,416	Bentonite	
2,418	Coal, bentonite, and lignitic shale	
2,429	Dark brown shale, with 6-inch bentonite at 2,421, and grading to sandstone in lower 2 feet	
2,530	"Verdigris" sandstone. (Named by S. E. Slipper from outcrop in Verdigris Coulee)	

In the foregoing section there are at least three coal-bearing horizons. The first of these, from 2,188 to 2,214 feet, consists principally of dark gray to brown carbonaceous shale with thin gray sandstone lenses. At the top of this zone is a *Unio* bed. The second horizon, between 2,352 and 2,373 feet, has more coal near the top, but shale predominates. The third and most important horizon occurs from a depth of 2,392 to 2,418 feet. The top of this zone is marked by a 2-foot bed of bentonite below which there is 20 feet of dark brown, carbonaceous shale containing much coal. From 2,414 to 2,415 feet and 2,416 to 2,418, there are coal seams. From 2,415 to 2,416 feet, and in the coal last mentioned there are conspicuous bentonite beds. This coaly member is correlated with the McKay seam, which is mined near the town of Milk River. Below the McKay coal there is 11 feet of soft, friable, dark brown car-

bonaceous shale which contains sulphur gas. This shale rests with sharp contact on the Verdigris sandstone. The sandstone is gray, coarse-grained, very calcareous, and contains gas. It has a thickness of 101 feet and the contact with the underlying Pakowki equivalent is gradational.

Pakowki equivalent.—The Pakowki formation, as known from outcrops and well samples farther east, is different from beds in the same stratigraphic position at Spring Coulee. In the east the formation is a dark, marine shale, which thins westward. At Spring Coulee its equivalent consists of brown to gray, carbonaceous shale which contains coal and one non-marine fossil, *Unio mclearni*. These factors suggest that the rocks are of fresh-water origin, or at least brackish. The area, therefore, is believed to have been one of continental or littoral sedimentation, lying west of, or near, the western shore line of the Pakowki sea.

PAKOWKI EQUIVALENT SECTION

Depth in Feet	*Description*
2,530	Top of section
2,570	Brown to gray carbonaceous shale containing coal and *Unio mclearni*

Milk River formation.—This part of the Cretaceous, which was not cored, is represented by 530 feet of light gray, limy, coarse-grained sandstone, and gray-green to dark gray shales. Within the upper 300 feet, the formation consists of sandstone with about 25 per cent gray-green and 25 per cent dark gray shale; whereas the lower 230 feet contains only a trace of gray-green shale. It may be seen from this that the distinction between the upper and lower members depends on the gray-green shale content, although this distinction is mainly arbitrary. Another distinction is the appearance of a pepper-and-salt sandstone from 2,870 to 2,900 feet. The upper and lower contacts of the formation are poorly defined, as they are gradational with the overlying and underlying formations.

MILK RIVER SECTION

Depth in Feet	*Description*
2,570	Light gray limy sandstone with about 25 per cent dark gray shale and 25 per cent gray-green shale. (Includes Upper Eagle of Montana)
3,100	Light gray sandstone with 25 per cent dark gray shale and minor amounts of gray-green shale (Lower Milk River); Virgelle of Montana

COLORADO FORMATION

Upper member.—The change from Milk River sandstone to Colorado shale is gradual and the contact can not be definitely determined. How-

ever, in the rotary cuttings a change is noticeable at approximately 3,100 feet, and at 3,160 feet the formation is shale. From this depth to 4,200 feet, the sediments are mainly gray-black, slightly sandy shale, containing thin bentonite beds, ironstone concretions, pyrite crystals, calcite, and aragonite. At a few horizons the shale contains much sandstone, sufficient in some places to constitute the major part of the rotary cuttings. The upper of these sandy beds, between 3,300 and 3,360 feet, may be equivalent to the Medicine Hat gas sand. This sand contains solidified hydrocarbons.

Blackleaf member.—The lower 767 feet of the Colorado formation contains considerably more sand than the upper part. It has been termed the Blackleaf member in Montana. Its upper limit is not sharply defined.

Four of the sandstones of the Blackleaf member are worthy of mention. The highest of these, which occurred from 4,480 to 4,490 feet, contained an appreciable volume of gas. It has not been correlated with sands in other wells. The second sand was encountered from 4,655 to 4,680 feet, the upper 7 feet of which contained oil. This sand is fine-grained, well cemented, slightly micaceous, and has a porosity of 9 per cent. It is closely correlative with the Bow Island gas sand. The third sand was encountered from 4,715 to 4,743 feet. This is a gray, coarse-grained, non-coherent sand, the lower 5 feet of which is porous and water-bearing. The fourth sand occurred between 4,758 and 4,796 feet. This is a gray, medium-grained sandstone containing water at the top, where it is uncemented. Below the fourth sand the Blackleaf consists mainly of gray-black shale with a few fragments of green shale, and is in sharp contact with the Blairmore-Kootenay formation at a depth of 4,967 feet. Six feet above the contact the core contains pellets of green shale embedded in a matrix of gray-black sandy shale.

COLORADO SECTION

UPPER COLORADO SECTION

Depth in Feet	*Description*
3,100	Top of section
3,160	Transition zone; contains 60 per cent gray-black shale and 40 per cent gray sandstone
3,300	Gray-black shale with some sand, bentonite, and ironstone
3,360	Medicine Hat gas sand (?). Shaly sandstone containing hydrocarbons which give ether cut
4,200	Gray-black shale with sandy lenses; traces of bentonite, pyrite, aragonite, calcite, chert, and ironstone

BLACKLEAF MEMBER OF COLORADO

4,200	Top of section
4,390	Gray-black shale 75 per cent; dark gray sandstone 25 per cent
4,410	Grit bed. (Similar to base of Benton, Turner Valley)
4,480	Gray-black shale 70 per cent; dark gray to gray sandstone 30 per cent
4,490	Gas sand
4,655	Gray-black shale with green shale at 4,520 feet
4,680	Bow Island gas sand (?). Gray, indurated, medium-grained sandstone
4,715	Gray-black shale with green shale at 4,706 feet and 4,711 feet
4,743	Gray, coarse-grained sandstone
4,758	Gray-black shale
4,796	Gray sandstone
4,850	Gray-black shale with thin sand lenses
4,861	Dark gray sandstone
4,967	Gray-black shale with thin sand lenses and a few fragments of green shale

BLAIRMORE FORMATION

The formation has a total thickness of 675 feet. It consists of about 60 per cent green shale, 22 per cent gray shale and 18 per cent of gray to green-gray sandstone. Within the green shales there are a few beds of maroon and variegated shales, none of which is thicker than 2 feet. This section differs from sections in the Red Coulee and Kevin-Sunburst oil fields, for in those fields there are prominent sandstones, particularly in the basal part, which contain oil and gas, and maroon shales are outstanding marker beds. The base of the formation is marked by a 2-foot bed of chert conglomerate.

BLAIRMORE SECTION

Depth in Feet	*Description*
4,967	Top of section
5,100	Green shale section with gray sand lenses
5,160	Medium gray sandstone 50 per cent; gray shale 25 per cent; green shale 25 per cent
5,212	Green and dark gray shale
5,240	Gray sandstone
5,250	Black carbonaceous shale containing coal
5,555	Green shale 60 per cent; dark gray shale 15 per cent; gray sandstone 20 per cent; red shale 5 per cent
5,605	Dark gray sandy shale containing fish scales (*Cycloides*) and light gray limestone containing volcanic ash or sponge spicules (?). Probably marine
5,640	Variegated shale with *Unio hamili* and *Corbula onestae*? bed at 5,625 feet. Fresh-water
5,642	Chert conglomerate; basal member of Cretaceous. Base Vanalta sand Red Coulee

The upper 588 feet of the section, from 4,967 to 5,555 feet, consists of alternating beds of shale and sandstone. Within this division, the most conspicuous bed is a carbonaceous shale, from 5,240 to 5,250 feet, which contains some coal. Maroon shales occur at 5,046-5,047, 5,060-

5,061, 5,361-5,362, and 5,459-5,461 feet. The fossil record comprises fresh-water flora only. These, together with the coal and maroon shales, indicate continental deposition for this division.

The part of the section from 5,555 to 5,605 feet contains dark gray sandy shales and a 6-foot bed of limestone, from 5,579 to 5,585 feet. The shales are similar to those of the Blackleaf and contain fish scales (*Cycloides*). The limestone contains volcanic ash[1] or sponge spicules[2] or both. It is thought that the fish scales and spicules suggest marine deposition. The lower part, including the basal 37 feet of the formation, from 5,605 to 5,642 feet, contains 35 feet of shales resting on 2 feet of chert conglomerate. The shales are gray-green, dark gray, purple, and red. At 5,625 feet two species of non-marine fossils, *Unio hamili* and *Corbula onestae?*, were found. The conglomerate contains black chert pebbles, having an average diameter of 1 millimeter and a maximum diameter of 2 centimeters. They are rounded to subangular in form. The matrix is soft non-calcareous clay containing disseminated grains of pyrite. This bed is similar, in its megascopic appearance, to that cored in Alberta Petroleum Consolidated's well No. 1 at Red Coulee, where it is regarded as marking the base of the Cretaceous system.

JURASSIC

Fernie formation.—The Fernie formation, which is the approximate time equivalent of the Ellis, as recognized in Montana, has a thickness of 323 feet. It consists mainly of greenish black, calcareous, thin-bedded shales in which *Belemnites* are plentiful. There are several thin limestone bands, ranging in thickness from 2 inches to 1 foot within the shales. The upper 25 feet of the formation is brown, shaly sandstone (brown ribbon sand), and the basal 54 feet is mainly limestone. *Belemnites* and glauconite are conspicuous in the upper 15 feet of this basal member. The lower 37 feet, which is a hard, gray, cherty limestone containing oil and gas, rests on limestone which is probably Paleozoic in age.

The Fernie section may be conveniently divided into four units. The upper, from 5,642 to 5,667 feet, is brown, shaly, laminated, fine-grained, micaceous sandstone. Pyrite concretions are plentiful. The unit seems to be correlative with the brown ribbon sandstone of Turner Valley. The second unit, from 5,667 to 5,911, consists of greenish black shales with glauconitic beds. Coal and bentonite occur in the shale at 5,687 feet and a few fragments of red shale and pyrite crystals occur at

[1] A. J. Goodman, personal communication.

[2] J. A. Allan, personal communication.

FERNIE SECTION

Depth in Feet	*Description*
5,642	Top of section
5,667	"Brown ribbon" sandstone (Turner Valley Dalhousie)
5,911	Dark gray shale containing sporadic *Belemnites;* thin, gray limestone bands, total 3 per cent of section; glauconitic shale (5,687 and 5,810-17 feet). Coal and bentonite (5,687 feet). Traces of red shale and pyrite. Fish scale (5,750 feet). *Astarte?* (5,796 feet). *Pleuramya* cf. *obtusiporata*, 5,818 feet (Upper Jurassic fossil)
5,918	Gray-black shale containing *Belemnites*, pyrite, and glauconite
5,926	Gray massive limestone containing *Belemnites*, glauconite, and oölitic pyrite
5,928	Gray-black shale containing pyrite
5,965	White to brown, sandy, cherty, mottled limestone with rhynchonellid brachiopods at top

widely separated intervals. Fossils are not uncommon, particularly *Belemnites*. The third unit, from 5,911 to 5,928 feet, comprises 7 feet of gray-black, pyritiferous and glauconitic shale containing *Belemnites;* 8 feet of gray massive limestone, bearing glauconite, pyrite, and *Belemnites;* and 2 feet of gray-black shale, containing much pyrite. The fourth unit, from 5,928 to 5,965 feet, is a white to brown, sandy, cherty limestone. It is finely crystalline and contains many vugs, in which calcite and solidified hydrocarbons are common. The basal 10 feet contains thin beds of black shale in dark limestone. At a depth of 5,928 feet four specimens of rhynchonellid brachiopods were obtained. Imperfect preservation of these fossils does not permit specific determination, consequently the age of this limestone unit is not definitely settled. It may be Paleozoic, though its lithologic appearance conforms closely with basal Jurassic limestone exposed on the east butte of Sweetgrass Hills in Montana. Gas occurs throughout the limestone and several feet of core contained oil showings.

PALEOZOIC

Madison.—From 5,965 to 5,970 feet, which is the present depth of the well, the formation consists of very hard, cream-colored cherty limestone, which is regarded as Madison in age. Further drilling may furnish information which will definitely determine the age of this limestone.

CORRELATION

The Spring Coulee well, which is located between areas previously drilled in the foothills on the west and the plains on the east, suggests interesting correlations between these areas. The Cretaceous section, down to the base of the Colorado shale, is similar to that of the plains, although the Pakowki equivalent is of continental origin rather than of

marine, and the formations in general are thicker. The Pale beds-Foremost section is about 200 feet thicker than it is on the east, and its basal member, the Verdigris sandstone, has a thickness of 101 feet, which is much greater than elsewhere. The Colorado shale is slightly thicker and its lowest member, the Blackleaf, contains several prominent sandstones. Below the Colorado, the formations correspond more closely with sections in the foothills than with sections in the plains. This feature is particularly true in the Fernie.

In the Blairmore formation, equivalents of the Sunburst sand of Montana and the "Venalta sand" of Red Coulee seem to be shale. The base of the formation is marked by a chert conglomerate, which seems to be present in both Turner Valley and Red Coulee. In Turner Valley this conglomerate separates the Dalhousie sand into two units, the "gray Dalhousie" sand above and the brown ribbon sandstone below. In Red Coulee the conglomerate lies at the base of the Vanalta sand. Hence, the gray Dalhousie at Turner Valley and the Vanalta sand in Red Coulee are probably equivalent. The conglomerate at Spring Coulee separates two formations which are entirely different lithologically. A widely distributed chert conglomerate in the foothills has been used to separate the Blairmore from the Kootenay formation.[1] It is believed that the conglomerate in the well at Spring Coulee may be correlative with that mentioned in the foothills. For this reason the section above the conglomerate and below the Colorado is thought to be Blairmore in age.

Brown ribbon sandstone bands have been recognized at the following localities in the foothills: Canyon Creek; at several places in the Brazeau Range area; in the Nikanassin Range area;[2] the Highwood; and Turner Valley.[3] The age of these brown sands is a matter of dispute, for they have been referred to the Fernie as well as to the Kootenay formation of the disturbed belt. They have not been recognized as such in the plains east of Spring Coulee, although the brown shale below the Sunburst sand in Montana may represent the same zone. As the brown ribbon sandstone at Spring Coulee resembles them, it may be Kootenay in age, but its transitional contact with underlying Fernie shale militates against this theory. If this is Fernie, the Kootenay is entirely lacking in the plains.

[1] J. S. Stewart, "Geology of Disturbed Belt of Southwestern Alberta," *Geol. Survey of Canada Mem. 112* (1915), pp. 25-31.

[2] J. B. Webb, personal communication.

[3] P. D. Moore, personal communication.

STRATIGRAPHY OF SPRING COULEE WELL SUPPLEMENTARY PAPER[1]

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ABSTRACT

Since Yarwood wrote his paper on the "Stratigraphy of Spring Coulee Well," in which he gave the section down to the depth of 5,970 feet, the well has been completed at a depth of 6,191 feet. Record of the additional information is given so that the log may be complete. Recent information as to the age of the limestone is included.

All strata below 5,935 feet in the well are limestone, and are now regarded as of Madison (Mississippian) age. Beds which were formerly considered, on lithologic evidence, to be Jurassic are now classified as Paleozoic, as a result of recent microscopic studies. Examination of thin sections by A. J. Goodman[3] has shown secondary silica in the limestone at 5,940 feet. The deposition of secondary silica within the limestone is considered to have occurred within the leached limestone zone by waters rich in alkaline silicates which washed over the Paleozoic land mass before marine Jurassic time. All the limestone below 5,965 feet is lithologically similar to the Madison. Bryozoans from 5,972 and 6,007 feet were determined by R. S. Bassler[4] to indicate Mississippian age. As there are no marked lithologic differences in the sediments, and no breaks, which might be regarded as formational boundaries between 5,935 and 6,191 feet, all of the section is regarded as Madison.

The most remarkable features of this section are the exceptional amount of soft, porous limestone in it and a scarcity of chert, as compared with Madison sections from other wells. The drilling was easier than is ordinarily experienced in the Madison, as much as 5 feet an hour often

[1]Published with the permission of the Frontier Developments, Ltd. Manuscript received, May 18, 1931.

[2]Geologists with the Frontier Developments, Ltd. Introduced by Theodore A. Link.

[3]Personal communication from A. J. Goodman, office of the supervisory mining engineer, Immigration Building, Calgary, Alberta.

[4]Personal communication from R. S. Bassler, Smithsonian Institution, Washington, D. C.

JURASSIC (FERNIE)
MISSISSIPPIAN (MADISON)
5910
5920
5930
5940
5950
5960
5970
5980
5990
6000
6010
6020
6130
6150
BLACK SHALE, BELEMNITES, PYRITE
3' GRAY LIMESTONE, BELEMNITES
2' BLACK SHALE, GLAUCONITE
4' GRAY LIMESTONE, BELEMNITES
GAS SHOW SULPHUR ODOR
3' DK. GRAY LIMESTONE GLAUCONITIC, BELEMNITES
3" PYRITE AT BASE
2' GRAY SHALE, MUCH PYRITE
7' NO RECOVERY
4' LIGHT GRAY LIMESTONE, CHERT BANDS
SECONDARY SILICA (GOODMAN)
4' BROWN SANDY LIMESTONE, CHERTY
HEAVY OIL SATURATION
3' NO RECOVERY
9' LIGHT GRAY CRYSTALLINE LIMESTONE WITH
CHERT, IRON SULPHIDE AND PYROBITUMEN
1' SANDY LIMESTONE
FRAGMENTAL RECOVERY SANDY LIMESTONE
3' GRAY LIMESTONE WITH 3" BLACK LIMY SHALE
3' DARK GRAY SHALY LIMESTONE
3' DARK GRAY LIMESTONE
2' LIGHT GRAY CRYSTALLINE LIMESTONE
CRINOID AND MISSISSIPPIAN BRYOZOA
4' NO RECOVERY
OIL SATURATION
8' LIGHT GRAY CRYSTALLINE LIME
STYLOLITIC STRUCTURE, PYROBITUMEN
16' NO RECOVERY
DRILLED SIMILAR TO ABOVE LIMESTONE
4' HARDER DRILLING
6' FASTER DRILLING
DITCH SAMPLE-GRAY LIMESTONE, SAND AND SHALE
LIGHT GRAY LIMESTONE CHERTY STYLOLITIC
IRON SULPHIDE WITH TRACE PYRITE
2" DARK GRAY LIMY SHALE
HARD DENSE LIMESTONE, CHERTY, STYLOLITIC
MISSISSIPPIAN BRYOZOA (BASSLER)
16" VERY HARD CHERTY LIGHT GRAY LIMESTONE
4' LIGHT GRAY COMPACT CRYSTALLINE LIMESTONE
5' DARK GRAY LIMESTONE VERY POROUS CORAL Diphyphyllum
GOOD OIL SATURATION DARK COLOR DUE TO PYROBITUMEN
12' NO RECOVERY
6021 TO 6131 15% CORE RECOVERY WITH DITCH SAMPLES.
SOFT LIGHT GRAY TO WHITE CRYSTALLINE LIMESTONE,
DOLOMITIC WITH ALMOST PURE DOLOMITE AT BASE.
POROUS BY DOLOMITIZATION INCREASING
WITH DEPTH
FOSSILIFEROUS MAINLY BRYOZOA WITH CRINOID STEMS
STYLOLITE STRUCTURE AT 6177
SULPHUR WATER INCREASING TOWARD BOTTOM UNDER
2200 LBS. PRESSURE PER 36 INCH
AVERAGE DRILLING TIME - 1 HOUR TO 4 FEET
HARDER BEDS AT 6033 TO 6038
DENSE LIMESTONE WITH CHERT 6059 - 6065
TOTAL DEPTH 6191

FIG. 1.—Log of limestone section at bottom of Spring Coulee well. Depths shown in feet.

being made. From 5,935 to 5,970 feet the limestone is fairly hard and dense. Below that depth it is increasingly soft and porous. The denseness of the upper zone is probably the result of cementation from silicious and calcareous circulating waters of pre-Jurassic time. The porosity of the lower zone is probably the result of dolomitization.

Most of the limestone is white to light gray, exceptions occurring in only a few spots where iron sulphide[1] and pyrobituminous material make it darker gray. Above 5,970 feet the limestone is finely crystalline and dense. From 6,009 to 6,016 feet and from 6,030 to 6,059 feet it is also finely crystalline but porous. It is slightly sandy from 5,954 to 5,963 feet. In other parts it is coarsely crystalline, exceedingly so from 5,970 to 5,984 feet. The extreme hardness of parts of the limestone is caused by the presence of chert, either in the form of nodules ranging from ¼ inch to 3 inches in diameter, or as thin bands. Chert occurs sparingly throughout the greater part of the upper zone, but is plentiful at the upper and lower limits of that zone, or from 5,935 to 5,943 feet and from 5,963 to 5,970 feet. In the soft zone it occurs at the following depths: 6,004 to 6,016, 6,033 to 6,038, 6,059 to 6,065, and 6,117 to 6,118 feet. In this zone dolomitization seemingly increases downward to a depth of 6,172 feet, where it approaches a theoretically pure dolomite, as shown by analyses by W. P. Campbell[2] and A. J. Goodman.[3] Campbell's qualitative chemical analysis showed the percentage of magnesium to be very large, but Goodman's stain test of thin sections showed only minute fractions of the sections to be calcium carbonate.

Fossil bryozoans are plentiful in the soft zone. Crinoids and corals are also present. Dolomitization around these has caused much porosity. Well developed styolitic structure was observed at the following depths: 5,979, 5,992, 6,003, 6,009, 6,012, 6,035, and 6,177 feet. Vugs are common in the dense parts of the limestone. They range in size from ⅛ inch to ½ inch in diameter, and are invariably lined with small crystals of calcite coated with pyrobitumen.

The preponderance of opinion among Alberta geologists is, that the greater part of this section of Madison limestone is younger than that found in other plains wells east and north of Spring Coulee. This gives added evidence that the planation, which occurred during the

[1]Analysis by W. P. Campbell, office of supervisory mining engineer, Immigration Building, Calgary, Alberta.

[2]*Op. cit.*

[3]*Op. cit.*

interval between Paleozoic and Jurassic time, was progressively deeper into the Paleozoic sediments in a northeasterly direction.[1] All of the cores from 5,937 to 6,033 contained live oil of 31.2° Bé. gravity. The best saturation was from 5,946 to 5,955 feet. Gas bubbled from most of these cores after they were removed from the barrel. This situation is similar to that in the Kevin-Sunburst field, but different from that found in most southern Alberta wells, in that they have generally encountered barren limestone in the upper part of their Madison sections.

Bailing tests made at 5,970, 5,994, 6,009, and 6,053 feet showed that there was very little pressure, either gas or hydrostatic, in the zone of oil saturation. Part, if not all, of the dolomite below 6,055 feet bears sulphur water. The fifth bailing test at 6,191 feet showed the water column to be 5,263 feet high, or under a pressure of more than 2,200 pounds per square inch.

[1]Theodore A. Link, "Alberta Syncline, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931).

INVERTEBRATE PALEONTOLOGY OF SOUTHERN PLAINS OF ALBERTA[1]

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ABSTRACT

This discussion deals with faunas of the Cretaceous formations exposed in the plains of southern Alberta. Faunas older than the Milk River sandstone are not discussed. Local occurrences of fossils have made detailed paleontologic correlations in Alberta decidedly difficult. The marine, fresh-water, and brackish-water faunas are fairly constant and show little variation throughout Montana time, although some forms may be ascribed to definite horizons. This is particularly true of the Pakowki and Bearpaw shales, which are also definite lithologic units. The most plentiful and typical fossils are described and illustrated.

Most of the formations underlying the southern plains of Alberta may be correlated with the Montana division of the Upper Cretaceous. Later formations of Paleocene age are present, but they are, for the most part, of minor significance and their separation from the highest Cretaceous beds on invertebrate fossil evidence is doubtful. For this reason, we may limit ourselves, in the scope of this paper, to the Montana faunas.

The division of Montana time into smaller units on paleontological evidence has not been attended with the same success as has that of Colorado time. Ammonites, the great time markers of the Mesozoic, become scarce in the highest Cretaceous beds, and such species as are obtained in southern Alberta seem to have a long time range and have not, so far, proved useful in the demarcation of limited zones. Though they could be so employed, their scarcity would militate against their use by the practising geologist.

Other types of fossils do not seem to be limited in their vertical distribution. The lowest marine beds of the Montana contain a fauna which can be duplicated, for the most part, in the highest marine beds. Fossils are generally scarce in the marine beds and any discrepancy be-

[1]Presented before the Alberta Society of Petroleum Geologists, April 18, 1931. Manuscript received, May 18, 1931.

[2]Associate professor of geology, University of Alberta.

tween faunas of different formations may be due to the exigencies of collecting rather than to a distinct faunal change.

Differences in faunas, of course, do occur in the Montana formations, but they are the result of differences in habitat rather than of difference in age. In Montana time the sea was oscillatory in southern Alberta, as a result of the initiation of orogenic movements in the Rocky Mountain geosyncline on the west. Much coarse detritus was deposited, probably as large deltas along the shore line. Such conditions resulted in variation of the fauna depending on the salinity of the sea. Consequently we distinguish marine, brackish-water, and fresh-water faunas and the three types may all be present in one formation. Marine conditions prevailed most strongly in Pakowki and Bearpaw time and most of the faunas of these formations are marine. In Belly River time true marine conditions probably prevailed for very limited periods in the lower part of the series, most of the faunas present in the Belly River being of fresh- and brackish-water habitat. In the St. Mary River formation marine conditions ceased to exist and the faunas are mostly of the fresh-water type.

Although the marine formations do not show any sequence of faunas by which the various units may be detected, the fresh- and brackish-water faunas present certain variations which may be of diagnostic value. It should be emphasized, however, that such faunas may change in character laterally and conditions prevalent in one locality may not persist throughout the whole area. In fact, it is the *local* occurrence of fossils that has greatly retarded detailed stratigraphic work in Alberta.

Although the marine fauna is fairly constant throughout Montana time, nevertheless, certain fossils are more prolific at definite horizons and it has been found practicable in limited areas to depend on the profusion of certain forms as horizon markers. Such a scheme must be used with considerable discretion, for it may confuse the uninitiated. In the following pages we have listed the most plentiful and typical fossils of the different formations.

Milk River sandstone.—The Milk River sandstone is of continental origin and a considerable part of the formation is undoubtedly of sub-

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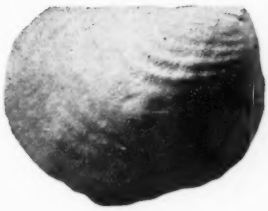
EXPLANATION OF PLATE I

(Marine species)

FIG. 1.—*Arctica ovata* (M. & H.).
FIG. 2.—*Acanthoscaphites nodosus* var. *quadrangularis* (M. & H.).
FIG. 3.—*Inoceramus barabini* Morton.
FIG. 4.—*Gervillia borealis* Whiteaves.

1

2



3

4

aerial deposition. Fossils are extremely rare. In two or three localities fossil plants have been obtained, but they are not sufficiently well preserved, as a rule, to be of much diagnostic value.

Pakowki shale.—Fossils are rare in the Pakowki shale and those that do occur are obtained also from higher horizons. The fauna is typically marine, but brackish-water forms have been reported from the passage beds at the top of the formation. It seems best in the confines of this paper to consider the passage beds containing the brackish-water fauna as a member of the overlying Foremost beds and reserve the name Pakowki shale for the purely marine deposits.

Only eight marine species have been reported from the Pakowki shale and of these five are extremely rare. The three species that occur most profusely are *Oxytoma nebrascana* E. & S., *Liopistha undata* M. & H., and *Baculites compressus* Say. The *Oxytoma* has a long time range extending from the Niobrara fauna of the Colorado group below to the Bearpaw shale above. It is probably at its maximum in the Pakowki shale. *Liopistha undata* appears first in the Pakowki shale and extends upward to the Bearpaw shale. It is reported as being more diagnostic of the Pakowki. *Baculites compressus* has a long time range through the Montana and was probably initiated in Pakowki time. Below this horizon *Baculites ovatus* is more plentiful. Though common in the Pakowki shale, *Baculites compressus* can not be considered in any way diagnostic of the formation, as it also occurs in considerable profusion in the Bearpaw.

The occurrence of these three species in considerable profusion is thought to be fairly diagnostic of the Pakowki shale, if at the same time we take into consideration the *absence* of other forms which occur somewhat plentifully in the Bearpaw shale.

Foremost and Pale beds.—The fauna of the Foremost and Pale beds include marine, brackish, and fresh-water species. Marine species are not plentiful and are largely limited in their distribution to the Foremost beds, and are found, for the most part, only in the lower part of that for-

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EXPLANATION OF PLATE 2

(Marine species)

FIG. 1 and FIG. 2.—*Baculites compressus* Say. Fig. 2 shows outline of cross section.
FIG. 3.—*Lunatia obliquata* (H. & M.).
FIG. 4.—*Protocardia subquadrata* (E. & S.).
FIG. 5.—*Liopistha undata* (M. & H.).
FIG. 6.—*Pteria linguiformis* (E. & S.).
FIG. 7.—*Oxytoma nebrascana* (E. & S.).
FIG. 8.—*Placenticeras intercalare* Meek.

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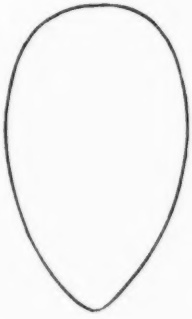

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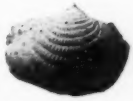

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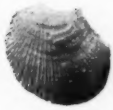

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mation. The brackish-water fauna occurs at a few definite horizons throughout the two formations, but is so plentiful when it is present that it far overshadows the fresh-water fauna, although the beds of fresh-water deposition are far in excess of those deposited in brackish water.

The most plentiful marine species found in the Foremost beds is *Mactra alta* M. & H. This species is also found in the Pakowki and Bearpaw shales, but is nowhere plentiful in these formations.

The most common brackish-water species are here listed.

Ostrea subtrigonalis E. & S.
Ostrea glabra M. & H.
Corbicula occidentalis M. & H.
Corbula perundata M. & H.
Corbula subtrigonalis M. & H.
Corbula perangulata Whiteaves
Melania whiteavesi Stanton
Velatella rectistriata Dyer

These fossils are so plentiful that many of them form beds as much as 3 feet in thickness; in fact the *Ostrea* and *Corbula* beds are probably the best horizon markers in the Belly River series.

The most common fresh-water fossils are as follows.

Unio danae M. & H.
Sphaerium planum M. & H.
Viviparus conradi M. & H.
Campeloma praecursa Dyer
Physa canadensis Whiteaves

The fresh-water forms are more evenly dispersed throughout the Pale and Foremost beds, but beds as much as a foot in thickness composed almost entirely of *Unio* do occur. It is very probable that the greater

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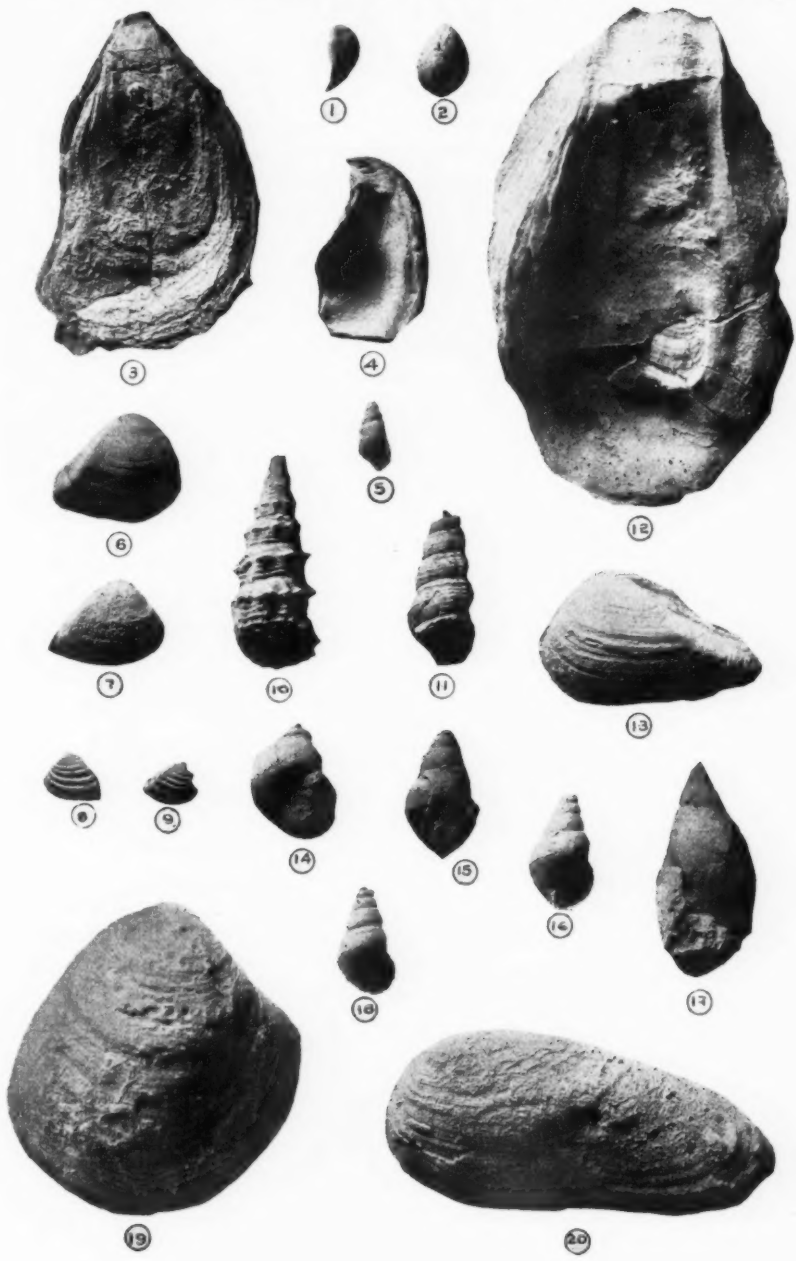
EXPLANATION OF PLATE 3

(Brackish- and fresh-water species)

FIG. 1 and FIG. 2.—*Velatella rectistriata* Dyer.
FIG. 3.—*Ostrea glabra* M. & H. A form typical of Pale beds.
FIG. 4.—*Ostrea subtrigonalis* E. & S.
FIG. 5.—*Campeloma limnaeiformis* (M. & H.).
FIG. 6 and FIG. 7.—*Corbula subtrigonalis* M. & H., showing variation in shape.
FIG. 8 and FIG. 9.—*Corbula perundata* M. & H.
FIG. 10.—*Melania wyomingensis* White.
FIG. 11.—*Melania whiteavesi* Stanton.
FIG. 12.—*Ostrea glabra* M. & H. A form typical of Foxhill sandstone.
FIG. 13.—*Corbula perangulata* Whiteaves.
FIG. 14.—*Viviparus leai* M. & H.
FIG. 15.—*Campeloma multilineata* (M. & H.).
FIG. 16.—*Campeloma producta* White.
FIG. 17.—*Physa canadensis* Whiteaves.
FIG. 18.—*Campeloma praecursa* Dyer.
FIG. 19.—*Corbicula occidentalis* M. & H. A large form typical of Foxhill sandstone
FIG. 20.—*Unio danae* M. & H.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number of the specimens of *Unio* collected from these formations have been obtained from these beds.

The distinction of Foremost and Pale beds on lithological grounds is not invariably reliable and the exact boundary between the two formations is located from personal judgment to a large extent. Fossil evidence is not of much assistance, but there are certain paleontological aspects of the two formations that should be stressed.

Ostrea subtrigonalis is more characteristic of the Foremost beds. It is known to occur at the very top of the Pale beds at Lethbridge, but it has no wide distribution in that formation. However, *Ostrea glabra* is characteristic of the Pale beds, though it occurs in the highest part of the Foremost beds in at least one locality. The common form is a very thin variety of the species, thus distinguishing the Pale beds from higher brackish and marine horizons where thicker varieties are more common. Of the *Corbulae*, *C. perangulata* is characteristic of the Pale beds, though it also occurs at higher horizons. Its occurrence in the Foremost beds is very irregular. *C. subtrigonalis* and *C. perundata* are more characteristic of the Foremost beds, where they occur in profusion. They are obtained from few higher horizons. In this respect *C. perundata* is the more diagnostic, as *C. subtrigonalis* has been obtained from some of the highest Montana beds.

From our present knowledge of the fresh-water fauna of the Pale and Foremost beds, it seems to have little diagnostic value. It is probable that in the future small varietal differences in some of the species may be of value in distinguishing the two formations.

Bearpaw fauna.—The Bearpaw shale contains a marine fauna that is representative of most of Montana time. Practically no marine species have been reported from higher or lower formations that do not also occur in the Bearpaw. The formation is more fossiliferous than other marine horizons and bears an extensive fauna. Many of the species found in the Bearpaw have not as yet been reported from other horizons, but it is doubtful if such species should be considered diagnostic of the formation. Montana marine species, as a whole, have a very long time range and their seeming absence from some horizons may be explained, in large part, by the exigencies of collecting.

The most common species found in the Bearpaw are here listed.

Inoceramus barabini Morton
Gervillia borealis Whiteaves
Protocardia subquadrata E. & S.
Pteria linguiformis E. & S.
Arctica ovata (M. & H.)
Lunatia obliquata (H. & M.)
Dentalium gracile M. & H.
Acanthoscaphites nodosus Owen
Placenticeras meeki Boehm
Placenticeras intercalare M. & H.
Baculites compressus Say

Most of the Bearpaw fauna has an erratic distribution through the formation. Such forms, however, as *Placenticeras* and *Arctica* are found, for the most part, at one definite horizon and are but sparsely represented otherwise.

Foxhills fauna.—The Foxhills sandstone represents the retreat of the Bearpaw sea, and the marine fauna is essentially the same as that of the Bearpaw. Brackish-water forms occur in greater profusion than marine forms in Alberta and seem to be more diagnostic of the formation. *Corbula perangulata*, *Corbicula occidentalis*, and a thick, heavy variety of *Ostrea glabra* are the principal pelecypods, and *Melania wyomingensis* White the chief gastropod. The peculiar form *Halymenites major* Lesquereux is plentiful in places and is especially diagnostic of the formation.

St. Mary River formation.—The fauna of the St. Mary River sandstone differs considerably from that of the Belly River formations, but is not essentially different from the overlying Cretaceous and Paleocene beds. It is essentially a fresh-water fauna. Such species as *Sphaerium planum* M. & H., *Unio danae* M. & H., and *Physa canadensis* Whiteaves have a long time range and occur in both Belly River and St. Mary River as well as in higher formations. The occurrence of such forms as *Sphaerium formosum* M. & H., *Viviparus leai* M. & H., *Campeloma producta* White, *Campeloma multilineata* (M. & H.), *Campeloma limnaeformis* (M. & H.), and *Valvata bicincta* Whiteaves in the St. Mary River are sufficiently diagnostic to distinguish that formation from the Belly River. They all continue, however, into the higher beds and there seems to be no sound paleontological basis by which the St. Mary River can be separated from the overlying Willow Creek or Paskapoo formations.

GEOLOGICAL NOTES

CLASSIFICATION OF ZWOLLE FIELD, LOUISIANA, AS LIMESTONE RESERVOIR

Study of limestone reservoirs has been one of the research projects of the American Petroleum Institute. Most of the information secured to date has been obtained through the work of W. V. Howard and associates at the University of Illinois. As oil in the Zwolle field of Louisiana is produced from a chalk series, a type of limestone, some of their data have been applied to the problems there.

Oil occurrence at Zwolle is very irregular. So extreme is this condition that nearly all good wells are offset by small producers or dry holes. Only about one out of five carefully chosen locations makes a well. This condition has deterred development and resulted in investigation of causes.

The oil has been regarded as coming from the so-called "Zwolle marl," overlying the chalk series proper, which latter, according to Hutson,[1] is probably Marlbrook and Annona in age. The marl probably represents the time interval from the Midway to the Marlbrook. However, Hutson and Norton[2] have said that evidence in cores submitted to them indicated that the oil does not come from the marl, but from the chalk. Cores of the marl are tight and non-petroliferous.

Subsurface study indicates that there has been structural deformation. Drilling reveals faults, fractures, cavities, and porous zones. The oil is produced from these. A short distance away, none whatever is secured. Whether there are fracture zones associated with a large fault or faults is not known, but this condition may exist.

Structurally, the Zwolle field collectively (several small areas of production are regarded as comprising Zwolle) seems to be located on a large southeastward-plunging anticline or nose, with indications of considerable faulting on the south side. Drilling to date has shown that though production is related to this regional "high," small pools may be

[1]E. B. Hutson, paleontologist, Standard Oil Company of Louisiana at Shreveport, Louisiana. Oral communication.

[2]R. D. Norton, paleontologist at the Shreveport office of The Texas Company. Oral communication.

found either high or low on it. The best spots of production need not be the highest structurally.

The oil is ordinarily obtained at or near the top of the chalk close to a possibly unconformable contact with the marl, but in places oil is encountered only after drilling into the chalk, perhaps where a fracture or cavity is crossed or entered.

The extent and continuity of the faults, fractures, and cavities is shown by the behavior of the oil and water. Thus, an oil well brought in as an offset to a producer may cause the latter to "go dead." Failures not drilled through the chalk generally show no water. If the chalk is completely penetrated, copious quantities of water are encountered in the sand underneath. Most producing wells soon make water. Analyses of this water and the water in the underlying sand are similar. It thus seems, as suggested by R. E. Heithecker,[1] United States Bureau of Mines representative now making a study of the field, that the fractures may extend completely through the chalk and that the water moves up through them.

H. H. Pier[2] made porosity tests on chalk cores, both from a dry hole offsetting a producer and from one not near a productive well. He found the average porosity was 14 per cent. These cores, however, showed no oil, although seemingly some could be expected.

Furthermore, Heithecker placed a barren piece of chalk core in Zwolle crude in November, 1930. When examined and broken open in March, 1931, the core had been completely saturated by capillary action, showing that oil can migrate through the barren chalk.

Comparison with producing chalk is difficult because, according to the writer's information, there is no such authentic core, although a fragment blown out of the Lide *et al.* Sabine Lumber Company's well No. 1 in Sec. 30, T. 8 N., R. 12 W., had a honey-combed and weathered appearance, and its porosity was evidently considerably greater than 14 per cent. Its weathered appearance suggests an unconformity, indicating that this chalk was once part of a land area.

To explain the absence of oil in adjacent chalk with 14 per cent porosity is somewhat difficult when seemingly oil can move through it. Perhaps the porosity, if there are extensive porous zones not connected with large fractures and faults, is discontinuous,[3] the tight zones acting as barriers in much of the formation. A porous zone only 2 feet thick can

[1]R. E. Heithecker, U. S. Bur. of Mines Shreveport office. Oral communication.

[2]H. H. Pier, chemist, Louisiana Dept. of Conservation, Shreveport, Louisiana.

[3]A. N. Murray, "Limestone Oil Reservoirs of the Northeastern United States and of Ontario, Canada," *Econ. Geol.*, Vol. 25, No. 5 (August, 1930), p. 453.

produce much oil, as shown in the Arbuckle limestone at Oklahoma City.[1]

The barren chalk cores indicate to the writer that the oil is not indigenous. Its high gravity of 40° Bé. may indicate that it migrated for some distance and was fractionated.[2] Perhaps the oil migrated in from the sand below the Annona chalk after subsidence and fracturing of the chalk and capping by the marl. It may be that the sides of the fractures, faults, and large and small cavities were sealed off by deposition of calcite before the old land area was submerged. Murray[3] noted such a condition in the Niagara limestone at Monon, Indiana. Hutson[4] reports he has found calcite-filled fractures in cores. This is one way of accounting for the absence of oil in porous dry cores.

In short, from the foregoing there is evidence that (1) the chalk series was once above water and had some secondary porosity developed before subsidence and capping by the marl; (2) that fracturing and faulting occurred because of crustal deformation; (3) that oil is found only in fractures and faults and in cavities and porous chalk adjacent to them; (4) that water is found only in those places; and (5) that oil may be found either high or low on the regional structure.

Application of these data under Howard's classification of limestone reservoirs[5] suggests that the Zwolle field should be placed in the fractured limestone group with the fracturing caused by crustal movement modified by some secondary porosity. It may thus really be a combination of two types.

HUGO R. KAMB

SHREVEPORT, LOUISIANA[6]

April 18, 1931

[1]Homer H. Charles, "Oklahoma City Field, Oklahoma," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 14, No. 12 (December, 1930), p. 1524.

[2]W. V. Howard and W. W. Love, "Some Properties of Limestone as a Reservoir Rock," *Econ. Geol.*, Vol. 25, No. 7 (November, 1930), pp. 721-22.

[3]*Op. cit.*, p. 453.

[4]Oral communication.

[5]W. V. Howard, "A Classification of Limestone Reservoirs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 12 (December, 1928), p. 1155.

[6]Present address, 2215 Russell Avenue, North, Minneapolis, Minnesota.

UNITED STATES GEOLOGICAL SURVEY BULLETIN CORRECTION

W. C. Mendenhall, acting director of the U. S. Geological Survey, desires to bring to the attention of Association members an error in the definition of the Moreno formation as published in the Survey *Bulletin 826*, the lexicon of California stratigraphy. The following copy of a correction slip to be inserted opposite page 52 in *Bulletin 826* will be sent to anyone, especially anyone who has already received that bulletin, on application to the Survey at Washington, D. C.

CORRECTION

Moreno formation.

Upper Cretaceous: Southern California (Diablo Range).

R. Anderson and R. W. Pack, 1915 (U. S. Geol. Survey Bull. 603). Upper formation of Chico group. Rests conformably on Panoche formation, the lower formation of Chico group, and is unconformably overlain by Cantua sandstone member of Martinez (?) formation. In the southern area it consists of foraminiferal and diatomaceous maroon and chocolate-colored shale and dark clay shale, with some interbedded sandstone, and has a maximum thickness of about 1,600 to 1,800 feet. In the northern area it contains less of the shale of truly organic origin and more clay shale and sandstone and is unconformably overlain by Tejon formation. Typically exposed in Moreno Gulch, on east flank of Panoche Hills, where it is 1,700 to 2,000 feet thick and composed predominantly of thin-bedded, rather brittle brownish and lavender-colored shales that weather into small bits and flakes. In lower part of formation are numerous beds of sandstone, locally containing poorly developed concretions and in general similar to the sandstone of Panoche formation. The upper half of formation is more nearly pure shale and contains a greater proportion of material of organic origin. Calcareous shale, limestone nodules, and layers of semiporcelaneous siliceous shale occur locally, and near top of formation is a zone of white platy diatomaceous shale about 200 feet thick, which is traceable most of way along face of Panoche Hills, Fresno County. Line between Moreno and Panoche formations is arbitrarily drawn at horizon where the sandstone beds that form the steep eastern slope of Panoche Hills dip beneath the predominantly shaly beds.

(To face p. 52, U. S. Geological Survey Bulletin 826)

REVIEWS AND NEW PUBLICATIONS

"Symposium on Salt Domes." *Jour. Inst. Petrol. Tech.* (London), Vol 17, Nos. 91 and 92 (May, 1931), pp. 252-383.

The symposium comprises primarily a series of papers which were presented at one meeting of the Institute and the ensuing discussion which occupied the next meeting. The printed symposium consists of twelve papers: four papers on the salt domes of the Persia-Palestine-Arabia-Egypt area, a good, although short, summary paper on the German salt domes, a summary paper on the American salt domes, three short geophysical papers on salt domes, and some papers on theory.

The most important papers are those by Lees, Harrison, Wade, and Dabell on the salt domes of the Near East and Egypt. The special value of the symposium lies primarily in the data, some of them entirely new, on those salt domes, and secondarily in the thoughts on salt-dome theory which the Persian salt domes have provoked in geologists who have studied them closely.

Murray Stuart's suggested theory of the secondary origin of salt-dome cap rock from its own premises is inapplicable to the cap rock of the American salt domes.

DONALD C. BARTON

HOUSTON, TEXAS
September 1, 1931

Field Geology. By FREDERIC H. LAHEE. Third edition. McGraw-Hill Book Company, New York, 1931. 789 pp., 538 illus., pocket size, flexible. Price, $5.00.

The development of geological science and the progress in geological method during the last 10 years are clearly and adequately indicated by a comparison of this recently published third edition of Lahee's *Field Geology* with the second edition of this well-known and widely used handbook, which appeared in 1923. The volume in hand is the result of very extensive revision and expansion of the earlier edition, and is especially noteworthy for its concise treatment of the several geophysical tools which the geologist has lately learned to use. It is a book which should be in the library of every field geologist and is an essential bit of field equipment for every survey party.

The first half dozen chapters are only slightly changed from the earlier edition. These deal with the different features of rocks, ranging from minute structures and markings to the larger field relations, with special emphasis on their interpretation in terms of origin. Numerous keys and tables are presented in an attempt to systematize the seeming disorder of nature, and to aid the field geologist in his diagnoses. Chapters VII and VIII are devoted to

folds and faults; these chapters include considerable new material and indicate that the author is thoroughly conversant with the many studies, recently made in field and laboratory, concerning the deformation of rocks. Metamorphic rocks, mineral deposits, and topographic features receive their due share of attention in this first half of the volume, designed to set forth the nature of the data with which the geologist should be familiar before he begins his field explorations. The section devoted to topographic maps and their interpretation is especially commendable.

It is, however, the second half of the book, the part dealing with field methods, which indicates the most radical improvement, both in Lahee's presentation and in the technique of the geologist. Certain topics, inadequately treated in the earlier editions, such as the manipulation of the telescopic alidade and the use of the plane table in geologic mapping, are here given full treatment. New procedures, such as airplane mapping, are well described and nicely evaluated. Subsurface surveying is considered almost exclusively from the point of view of petroleum geology, and its discussion includes a consideration of the use of heavy minerals, micropaleontology, chemical analyses, and geothermal data in geologic correlation. The problem of crooked holes and their bearing upon subsurface interpretations is handled in an admirable manner.

The section on geophysical methods is by no means a complete manual of instruction for those who work with torsion balance, seismograph, or magnetometer; instead, it is well calculated to give the geologist the understanding which ought to be his concerning the basic principles upon which these and allied instruments operate, their limitations and their accomplishments. Such knowledge ought to be a part of the equipment of every geologist who makes any pretence of keeping abreast of the times, for geophysical surveying is destined to make important contributions to many other departments of geology than those which are embraced in petroleum geology. Only lack of vision is to-day delaying the justifiable expansion of geophysical work, and that lack is rapidly being overcome as geologists get acquainted with the new tools. Lahee's manual may well be recommended to those who desire an introduction to them.

All in all, this discussion of field methods deserves the highest praise. The book should prove extremely useful to the field man of long experience as well as to the student and the less experienced geologist.

KIRTLEY F. MATHER

HARVARD UNIVERSITY
CAMBRIDGE, MASSACHUSETTS
September 1, 1931

Maurice Gignoux, "La tectonique des terrains salifères; son rôle dans les Alpes Françaises." *Centenaire de la Société Géologique de France; Livre Jubilaire, 1830-1930* (Tectonics of Saliferous Terrains as Applied to the French Alps. Centenary of the Geological Society of France; Jubilee Volume, 1830-1930), Vol. 2, pp. 329-60. G. E. Stechert and Company, New York. Price, unbound, 2 vols., $12.00.

The article is a general review of salt domes of the world, leading up to his thesis (Tectonique du Trias Salifère dans les Alpes Françaises, pages 350-59) that gypsum beds in the French Alps are residual salt domes. He believes that the salt has all been leached away and, in some places at any rate, that the gypsum from various domes, originating from beds of different ages, has reunited to form a single continuous bed. The basis for his argument seems to be the inclusion of pre-Triassic, Jurassic, and Cretaceous fragments in Triassic gypsum.

MARGARET C. COBB

NEW YORK, NEW YORK
August 12, 1931

Principles and Practice of Geophysical Prospecting. By A. B. BROUGHTON EDGE and T. H. LABY. Cambridge University Press (1931); The Macmillan Company, New York. Demy 4to. xiv + 380 pp., 261 illus. Price, $5.00.

This book is the report of the Imperial Geophysical Experimental Survey which was established jointly by the Commonwealth Government of Australia and the British Empire Marketing Board to test the geophysical methods of prospecting. Field investigations were made with the electric, magnetic, gravimetric, and, to a less extent, seismic methods on sulphide and other ores, graphite, lignite, saline waters, and geologic structures in fifteen areas widely separated in the six Australian states. Most of the surveys were over known deposits and structure.

The form of the report is somewhat like that of a text-book illustrated by field results. Part I gives an elementary exposition of the geophysical methods and the results of the surveys. Part II gives a technical discussion of the field procedure, design, and behavior of the apparatus and field equipment, interpretation of the results, and underlying principles of the methods.

A handicap which was recognized and a limitation to the conclusions lie in the absence of experienced applied geophysicists, except electrical geophysicists, and in the non-standard character of some of the instruments used.

The Imperial Geophysical Experimental Survey deserves much praise and Broughton Edge and Laby have written a readable, interesting, and valuable report which is a permanent contribution to applied geophysics. The reviewer warmly recommends this book to all geophysicists and to all geologists and engineers who are closely interested in geophysics.

DONALD C. BARTON

HOUSTON, TEXAS
September 1, 1931

RECENT PUBLICATIONS

COLORADO

"The Devonian of Colorado," by Edwin Kirk. *Amer. Jour. Sci.* (New Haven), Vol. 22, No. 129 (September, 1931), pp. 222-40.

GENERAL

"Das Wandern des Erdöls" (Migration of Petroleum), by O. Stutzer. *Intern. Zeits. f. Bohr., Erdölb. und Geol.* (Vienna), Vol. 39, No. 15 (August 1, 1931), pp. 113-17.

"Bemerkungen zum geoelektrischen Nachweis und zur Migration des Öls" (Observations on Geoelectric Proof and on Migration of Petroleum), by J. Königsberger. *Petrol. Zeits.* (Berlin), Vol. 27, No. 32 (August 5, 1931), p. 579.

GEOPHYSICS

"Die Bearbeitung und Deutung von Drehwaagenmessungen" (Revision and Interpretation of Torsion-Balance Surveys), by Hans Hlauschek. *Petrol. Zeits.* (Berlin), Vol. 27, No. 27 (July 1, 1931), pp. 510-20, 28 figs.

Theory of the Tectonical Gravimetric Investigation, by J. A. A. Mekel. Thesis for degree of doctor of technology at Delft, March, 1928. Translated from Dutch by M. Walter Pesman. Prepared through departments of mechanics and geophysics, Colorado School of Mines, Golden. For sale by F. B. Robinson, stationer, Golden, Colorado. 89 pp., mimeographed; illus. Price, $2.00.

PENNSYLVANIA

"Gas in the Tioga Region, Pennsylvania," by George H. Ashley, Stanley H. Cathcart, Bradford Willard, and Charles R. Fettke. *Pennsylvania Topog. and Geol. Survey Bull. 102* (Harrisburg, August 10, 1931). 28 pp., 2 maps. Mimeographed. Revision of edition of April 17, 1931.

RUSSIA

"Zur Geologie der ölführenden Schichten des Ural" (Geology of the Petroliferous Beds of the Urals), by N. Polutoff. *Petrol. Zeits.* (Berlin), Vol. 27, No. 32 (August 5, 1931), pp. 580-81.

TENNESSEE

"Geology and Ground-Water Resources of Western Tennessee," by F. G. Wells *et al.* Coöperative report by *U. S. Geol. Survey* and *Tennessee Geol. Survey* in manuscript form, which may be consulted at Washington, D. C., and at Nashville, Tennessee.

TEXAS AND LOUISIANA

"Oil and Sulphur Development in the Texas and Louisiana Gulf Coast Salt Dome Region," compiled and edited by G. C. Francisco, Jr., and Harry M. Sample. *Texas Gulf Coast Oil Scouts Assoc. and South Louisiana Oil Scouts Assoc. Bull. 1, 1930* (1931). Publication headquarters, 1418 Esperson Building, Houston, Texas. 128 pp., illus. 8 × 10 5/8 inches. Paper. Price, $3.50.

WYOMING

"The Significance of Geologic Conditions in Naval Petroleum Reserve No. 3, Wyoming," by W. T. Thom, Jr., and Edmund M. Spieker; with a section on "The Waters of the Salt Creek-Teapot Dome Uplift," by Herman Stabler. *U. S. Geol. Survey Prof. Paper 163* (1931), Supt. of Documents, Washington, D. C. 64 pp., 19 figs., 30 pls., 14 tables, index. Paper. Price, $1.25.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Memorial

KINGSLEY CAMDEN MITCHELL

Kingsley Camden Mitchell, associate member of the Association, was murdered June 12, near the city of Mier, state of Tamaulipas, Mexico.

According to one report from Mexico, Mitchell was fired upon and killed by Rufinio Solis, sixteen-year-old boy, who confessed to the murder, saying Mitchell had insulted him. Another report from Mexico states Rufinio Solis, infuriated because of the unfortunate shooting in Oklahoma of two cousins of President Ortiz Rubio, fired upon Mitchell while he was at work on an outcrop. According to the latter report, no words were spoken between Mitchell and Solis.

Kingsley Camden Mitchell was born in Camden, Maine, August 3, 1903. During his early years, the family moved to Carthage, Missouri, and in 1912 to Santa Barbara, California. He attended the Santa Barbara Grammar School until 1916 and from 1916 to 1920 attended the Santa Barbara High School. From 1920 to 1922 he was enrolled in the Santa Barbara Junior College, transferring to the University of California in 1922. His first two years at the University were spent in the College of Letters and Science. In 1924 he entered the College of Mining and majored in economic geology. He received his B. S. degree in May, 1927.

Mitchell was a member of Delta Chi general college fraternity, and a member of the honorary scholastic fraternity Tau Beta Pi.

Soon after graduating from the University of California in May, 1927, he was employed by the Rocky Mountain division of the Union Oil Company of California, with headquarters at Fort Collins, Colorado. During the summer of 1927 he worked in the capacity of assistant geologist in reconnaissance mapping on the "Western Slope" of Colorado. In the fall, he was given charge of test-pit exploration work in the Laramie basin in Wyoming, where he worked until November, 1928. In January, 1929, he was employed and sent to southern Mexico by the Richmond Petroleum Company, a subsidiary of the Standard Oil Company of California. He remained in southern Mexico nearly two years and was then transferred to northern Mexico, where his career so tragically ended.

The Association has lost a young personality that gave promise of going far in his chosen field of petroleum geology. He was always quietly determined to discharge his duties in the best possible manner. He had many original ideas and the keen intellect and good judgment to execute them.

Kingsley or "Killy" as his friends knew him, was serious-minded in regard to both his work and his recreation. He possessed a uniform temperament which even in periods of greatest stress could not be flustered. Although extremely studious, he was fond of competitive sports and was an able boxer. He loved music and spent his available time, when possible, in the cultivation of a very pleasing singing voice. Among his friends he was ever thoughtful and

this one trait alone has endeared him to all who were fortunate enough to know him intimately.

He is survived by his mother, Mrs. L. Read Mitchell, two sisters, Barbara and Mrs. H. Pimley, and a brother Gordon, who live in San Francisco; a brother, Donald, residing in Los Angeles; and a brother, Samuel Duffield, who is in the bond department of the Bank of America in San Jose, California.

C. E. MANION

SANTA PAULA, CALIFORNIA
August 19, 1931

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The annual meeting of the Geological Society of America, in coöperation with The American Association of Petroleum Geologists, will be held at the Mayo Hotel in Tulsa, Oklahoma, December 29-31.

A half day session of the technical program will be devoted to papers by members of the Association. All Association members are urged to attend this meeting. Reduced railroad rates have been granted.

Inquiries should be addressed to Frank R. Clark, general chairman, Box 2064, Tulsa, Oklahoma.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT, of Hainfeld Castle, Feldbach, Styria, Austria, has published a paper entitled, "Bemerkungen zur Oszillationstheorie Erich Haarman's," in the Zeitschrift of the German Geological Society, Vol. 83, No. 5 (1931).

DJEVAD EYOUB, consulting geologist, has returned from Tampico, Mexico, and may be addressed at 302 Furr Drive, San Antonio, Texas.

A. J. GOODMAN, recently with the Department of the Interior, Calgary, Alberta, Canada, has moved to "Melrose," Debdale Road, Wellingborough, Northants, England.

JAMES S. HUDNALL, of Hudnall and Pirtle, has moved from San Antonio to Tyler, Texas. The mail address is Box 740.

HENRY SCHWEER, of Norman, Oklahoma, may be addressed at Box 225, Demopolis, Alabama.

DAVID B. REGER, associate geologist of the West Virginia Geological Survey, has an article, "Pennsylvanian Cycles in West Virginia," in *Illinois State Geological Survey Bulletin 60*, pages 217-31.

HARRY P. STOLZ, formerly chief petroleum engineer with the Sunset Pacific Oil Company, and E. R. STANLEY, formerly petroleum engineer with the George F. Getty and MacMillian petroleum corporations, have opened offices at 719-723 Security Building, Los Angeles, California, for general practice in mining and petroleum engineering.

The American Petroleum Institute will continue studies in fundamental research in petroleum occurrence, recovery, and composition, for a period of two years. Project No. 4, "Origin and Environment of Source Sediments of Petroleum," is continued under the direction of PARKER D. TRASK, who will have two assistants, one at Washington and one at Tulsa. Particular attention will be given to the study of samples of possible source rocks from drilled and

drilling wells. Members of the advisory committee of the American Petroleum Institute on fundamental research on the occurrence and recovery of petroleum are: L. P. GARRETT, E. G. GAYLORD, K. C. HEALD, F. H. LAHEE, ALEXANDER MCCOY, C. V. MILLIKAN, K. B. NOWELS, R. D. REED, H. B. SOYSTER, H. D. WILDE, JR., and H. H. HILL, *chairman*. All these gentlemen except the last two are also members of The American Association of Petroleum Geologists.

RONALD K. DEFORD will teach geology at the Colorado School of Mines, Golden, the coming college year.

WARREN B. REED, consulting engineer, has changed his address from Morgan City, Louisiana, to 731 Royal Street, New Orleans, Louisiana.

KENNETH S. FERGUSON, formerly geologist with the Midwest Refining Company, Denver, Colorado, has been appointed geologist and engineer for the Potash Company of America with headquarters at Carlsbad, New Mexico.

J. M. VETTER, geologist, has given up consulting work and has assumed charge of the geological work for the Rio Bravo Oil Company, Houston, Texas.

LEON BOSSARD, whose consulting office is at Pestalozzistr. 37, Zürich 7, Switzerland, has returned to Europe after 5 years of exploration in New Zealand for the Australian Oil Companies.

The annual fall meeting of the Pacific Section of the Association will be held in Los Angeles, November 5 and 6. A part of the program will be a symposium on the structural history of California oil fields. C. M. WAGNER, 1003 Higgins Building, Los Angeles, is in charge of the program. All members of the Association are cordially invited to attend these meetings.

JULIAN HINDS, designing engineer for the metropolitan water district, talked on "The Colorado River Project and Metropolitan Aqueduct," at the luncheon of the Pacific Section of the Association, held at the Engineers' Club, Los Angeles, September 18.

W. H. WHITTIER, of Berkley, California, has accepted an appointment as geologist for the U. S. General Land Office, with headquarters at Denver, Colorado. His post-office address is Box 509.

The geologists working in East Texas met in Tyler, September 10, and formed the East Texas Geological Society. The following officers were elected: president, E. A. WENDLANDT; vice-president, W. C. THOMPSON; and secretary-treasurer, E. M. RICE, Box 22J, Van, Texas.

The Third International Conference on Bituminous Coal, Thomas R. Alexander, secretary, will be held at Carnegie Institute of Technology, Schenley Park, Pittsburgh, Pennsylvania, November 16-21.

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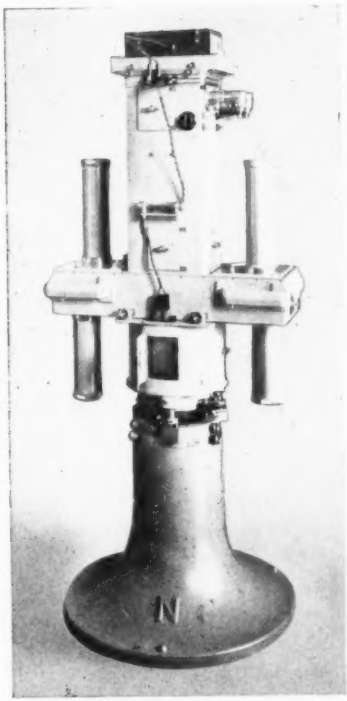

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